

Guide for Decontaminating Buildings,
Structures, and Equipment at Superfund Sites

PEI Associates, Inc., Cincinnati, OH

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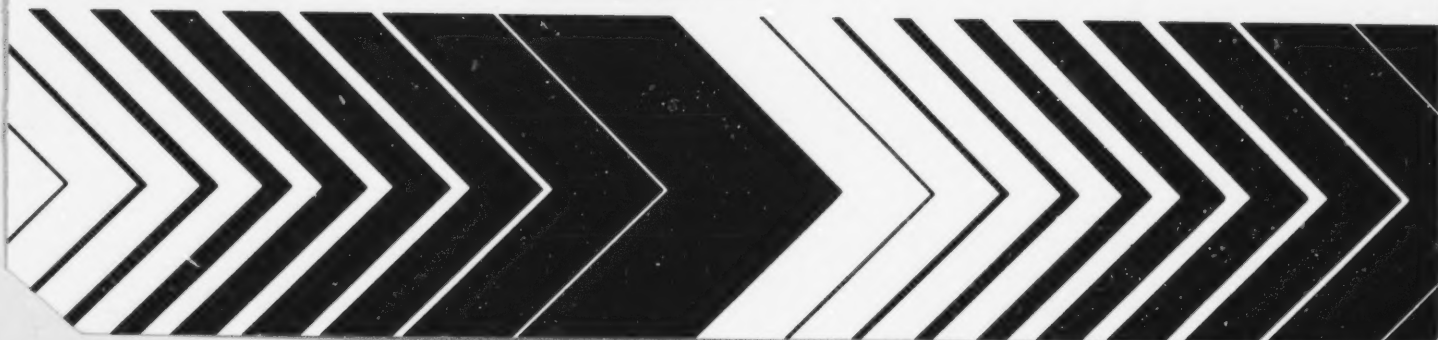
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AT SUPERFUND SITES

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DISCLAIMER

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FOREWORD

Today's rapidly developing and changing technologies and industrial products and practices frequently carry with them the increased generation of solid and hazardous wastes. These materials, if improperly dealt with, can threaten both public health and the environment. Abandoned waste sites and accidental releases of toxic and hazardous substances to the environment also have important environmental and public health implications. The Hazardous Waste Engineering Research Laboratory assists in providing an authoritative and defensible engineering basis for assessing and solving these problems. Its products support the policies, programs, and regulations of the Environmental Protection Agency, the permitting and other responsibilities of State and local governments, and the needs of both large and small businesses in handling their wastes responsibly and economically.

This report presents information on decontamination of buildings, structures, and equipment at Superfund sites. Decontamination methods, types of contaminants, site-specific technology selection, effectiveness evaluation, case studies, and worker health and safety are discussed. The intended audience for this document includes those involved in developing a decontamination strategy for cleanup of buildings, structures, and equipment at Superfund sites. For further information, please contact the Land Pollution Control Division of the Hazardous Waste Engineering Research Laboratory.

David G. Stephan, Director
Hazardous Waste Engineering Research Laboratory

ABSTRACT

This handbook describes methods of decontaminating buildings, structures, and equipment at Superfund sites. Types of contaminants most likely to occur in buildings and structures at remedial sites or on removal equipment such as drum grapplers or bulldozers include asbestos, acids, alkalis, dioxins, explosives, heavy metals and cyanides, low-level radiation, organic solvents, pesticides, and polychlorinated biphenyls.

Use of this general guide for developing a decontamination strategy will assist Superfund personnel in determining an efficient, practical, and safe course of action in a given situation. Steps in the process include 1) determining the nature and extent of contamination, 2) developing and implementing a site-specific decontamination plan, and 3) evaluating decontamination effectiveness. Step 1 includes querying former employees, searching old records, conducting a visual inspection of the site, and collecting/analyzing samples. Step 2 is further divided into the following steps: evaluating hazards, identifying the future intended uses of buildings, structures, or equipment, establishing decontamination target levels for the contaminants present, identifying and evaluating potential decontamination methods, selecting the most cost-effective method(s) for achieving the decontamination target levels, determining worker health and safety requirements (training, medical surveillance, personal protective equipment, site safety), writing the site decontamination plan, and hiring the contractor to initiate cleanup. Step 3 includes reinspecting the site after cleanup, collecting and analyzing samples, comparing the results to target levels, repeating or modifying the cleanup procedures as necessary, and determining the need for long-term monitoring. Descriptions of actual building decontamination efforts at both Superfund and non-Superfund sites are included as case studies.

The handbook contains descriptions of a number of example decontamination methods for treating or removing contaminants: asbestos abatement, absorption, demolition, dismantling, dusting/vacuuming/wiping, encapsulation, gritblasting, hydroblasting/waterwashing, painting/coating, scarification, solvent washing, steam cleaning, vapor-phase solvent extraction, acid etching, bleaching, flaming, drilling and spalling, microbial degradation, and photochemical degradation.

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SECTION 1

INTRODUCTION

BACKGROUND

Cleanup of the Nation's abandoned hazardous waste sites is the top environmental priority of the decade. In 1980, Congress passed the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA, or Superfund), which established a dual-phase program for responding to environmental problems caused by hazardous substances. The removal program involves cleanup or other actions that are taken in response to emergency conditions or on a short-term or temporary basis. The remedial program involves response actions that tend to be long-term in nature and that permanently remedy problem sites. The U.S. Environmental Protection Agency (EPA) is charged with implementation of the Superfund legislation.

To be eligible for remedial cleanup under Superfund, a site must be included on the National Priorities List (NPL). As of this writing, 538 sites appear on the NPL and an additional 248 sites have been proposed for inclusion on the list. In a Superfund reauthorization bill before the House (HR 5640), a mandatory cleanup schedule is being considered that would require EPA to list 1600 sites on the NPL by January 1, 1988, and to begin remedial investigations and feasibility studies at each site within 6 months of the date it is listed.¹

With the increasing level of Superfund activity has come a need for basic guidance on decontamination of buildings, structures, and equipment. Decontamination of these items is important in preventing the spread of contamination offsite and in reducing exposure levels to future users of the buildings or equipment. Also, a successful decontamination program can offset the high costs of dismantling and disposing of contaminated structures, while at the same time salvaging or increasing the value of the reconditioned buildings, equipment, or property. The objective of a decontamination program, therefore, is to return contaminated buildings, structures, and equipment to active, productive status.

In the fall of 1983, a survey was conducted of the decontamination activities at 50 selected Superfund sites across the country. The results of the survey, presented in Appendix A, revealed that the current state of the art in this area is not well developed. Removal equipment is generally steam-cleaned (typically, no testing is performed to verify contaminant removal), and buildings and structures are frequently torn down instead of being decontaminated. These findings clearly pointed to the need for basic guidance material dealing

Section 1/Introduction

with decontamination methods and their application to various contaminants and structural materials.

PURPOSE

This handbook was developed to assist EPA headquarters program offices and regional Superfund personnel in planning the restoration of sites with contaminated buildings, structures, and/or equipment, as required by the National Contingency Plan. Its purpose is twofold:

1. To provide general guidelines for developing a decontamination strategy.
2. To provide method descriptions of example decontamination techniques.

ORGANIZATION

The handbook is organized into three main sections (Sections 3, 4, and 5) and is supplemented by 11 appendices. Section 3 presents general guidelines for developing a decontamination strategy. Three principal steps and several substeps are identified and discussed under separate headings. Section 3 also introduces eight case studies (from the appendices) as examples of decontamination strategies that have been developed for both Superfund and non-Superfund sites.

Section 4 presents descriptions of example methods for decontaminating buildings, structures, and equipment. The methods are grouped according to their mode of action--physical/mechanical, solvent/extraction, chemical, and thermal. Developmental methods are also described. The following aspects are discussed for each method: general description, advantages, disadvantages, state of the art, variations, applicability, effectiveness, engineering, safety, waste disposal, costs, and future work required.

Section 5 describes the key elements necessary to ensure the health and safety of decontamination workers during site operations. Topics covered include personnel training, medical surveillance, personal protective equipment, and site safety.

Supplemental information is included in the appendices. Appendix A contains a tabular summary of the initial survey of decontamination activities at selected Superfund sites. Also included are site data summary forms for selected entries in the table. Appendix B describes methods of measuring contamination in or on buildings, structures, and equipment. Appendix C presents cost analyses of several of the decontamination methods described in Section 4. Cost estimates for equipment, materials, labor, overhead, etc.,

are based on a model building. Appendices D through K are case studies illustrating various decontamination strategies that have been implemented at both Superfund and non-Superfund sites. The subjects of the case studies are as follows: the town of Seveso, Italy; a state office building in Binghamton, New York; the Sontag Road area in St. Louis, Missouri; the One Market Plaza office complex in San Francisco, California; the Frankford Arsenal in Philadelphia, Pennsylvania; a New England office building; the Luminous Processes, Inc., facility in Athens, Georgia; and the Chemical Metals Industries, Inc., sites in Baltimore, Maryland.

SECTION 2

CONCLUSIONS AND RECOMMENDATIONS

CONCLUSIONS

This handbook has been prepared to assist EPA headquarters program offices and regional Superfund personnel in planning the restoration of sites with contaminated buildings, structures, and/or equipment. While this document provides much of the needed guidance for developing a decontamination strategy, the reader should be aware of three limiting areas in the current state-of-the-art technology.

First, surface and subsurface sampling techniques are not yet standardized. Sampling of contaminated equipment and structural materials is the foundation upon which a decontamination strategy is built and the means by which the effectiveness of that strategy is evaluated. Surface sampling generally employs a variation of the wet-wipe or dry-wipe technique as a means of assessing the nature and extent of contamination. This approach often suffers from two major deficiencies: variable collection efficiency and long sample turnaround time. Subsurface sampling techniques (e.g., corings) have not been validated for determining the depth of contaminant penetration in porous substrates.

Second, the applicability and effectiveness of the methods described in this handbook generally have not been documented. Many of the techniques were developed specifically for the U.S. Army's Installation Restoration Program and have not been applied or tested on all of the contaminant/structural material combinations encountered at Superfund sites. Pilot-scale testing of the methods on a site-by-site basis prior to full-scale implementation is recommended.

Third is the question of how clean is clean? This is often the most perplexing one surrounding decontamination activities. Decontamination target levels have been, and continue to be, established on a case-by-case basis by a variety of Federal, state, and local agencies. The EPA is in the midst of developing a novel site-by-site risk-assessment approach to determining the appropriate extent of remedy at Superfund sites. Draft guidance is currently undergoing review.

RECOMMENDATIONS FOR FUTURE STUDY

Standard surface and subsurface sampling techniques need to be developed for buildings and equipment. Such techniques should use readily obtainable

equipment and should be relatively inexpensive to perform. Sampling protocols should specify the materials and reagents needed, the procedures to be followed, the number of samples to be taken, the analytical methods to be used, and the quality assurance/quality control (QA/QC) procedures to be adopted. In cases where the contaminant of interest is very expensive to sample and analyze (e.g., dioxin), methods should be developed with other less costly sampling parameters and testing techniques that can indicate (with acceptable accuracy) the presence and level of the contaminant of interest. A matrix that identifies sampling techniques applicable to specific contaminant/structural material combinations would be useful.

Studies are needed to document the applicability and effectiveness of the decontamination methods presented in this handbook. Recommendations for further engineering development of existing technologies should be followed. New technologies should be evaluated and added to the handbook as they become available.

A formal, systematic approach needs to be developed for determining acceptable levels of contaminants in and on building and equipment surfaces. Related methods for determining acceptable levels of contaminants in soils at contaminated sites may be useful for developing such an approach. Examples of methods that should be evaluated include the multimedia environmental goals (MEG's), the composite hazard index, the preliminary pollutant limit values, and the monitoring trigger levels (MTL's).²

There will often be considerable merit in assuring that future owners of decontaminated buildings and structures on Superfund sites are made aware of the nature and levels of any residual contamination and of the cleanup methods used. Ensuring the transfer of such information from one site owner to the next will require a method for permanently recording this information. Regulations requiring the addition of such information to the property deed (as required in the deed of all RCRA-permitted facilities) may be a workable solution.

Finally, this document (especially Tables 1 and 2, Sections 3 and 4, and Appendix B) should be periodically updated to add the results of studies in the areas described above.

SECTION 3

DEVELOPMENT OF A DECONTAMINATION STRATEGY

For a decontamination program to proceed safely and cost-effectively, considerable effort should be devoted to development of a decontamination strategy. Strategy development involves three principal steps:

1. Determination of the nature and extent of contamination.
2. Development and implementation of a site-specific decontamination plan.
3. Evaluation of decontamination effectiveness.

As shown in the flow diagram (Figure 1), each step in the sequence entails several substeps. These steps and substeps are discussed in this section.

STEP 1. DETERMINATION OF THE NATURE AND EXTENT OF CONTAMINATION

Development of an overall decontamination strategy revolves around the proper identification and evaluation of the contaminants present. This knowledge is necessary for selection of decontamination methods that will effectively reduce the contamination to acceptable levels while providing adequate protection to workers. Remedial site investigations of buildings and structures should include a records search, visual inspection, and sampling survey to determine the nature and level of contaminants present. Equipment used in removal operations should routinely be decontaminated before leaving the site to minimize the spread of contamination.

Records Search

A knowledge of past operations at the site will generally yield information regarding the nature of contaminants likely to be present. Such information may be available through onsite records (operating logs, manifest records), reports of Federal or state site investigations, local fire and police departments, former employees of the facility, and neighboring residents or business employees.

Inspection

Visual inspection can identify areas of gross chemical contamination as well as reveal the condition or soundness of a building or structure. Such

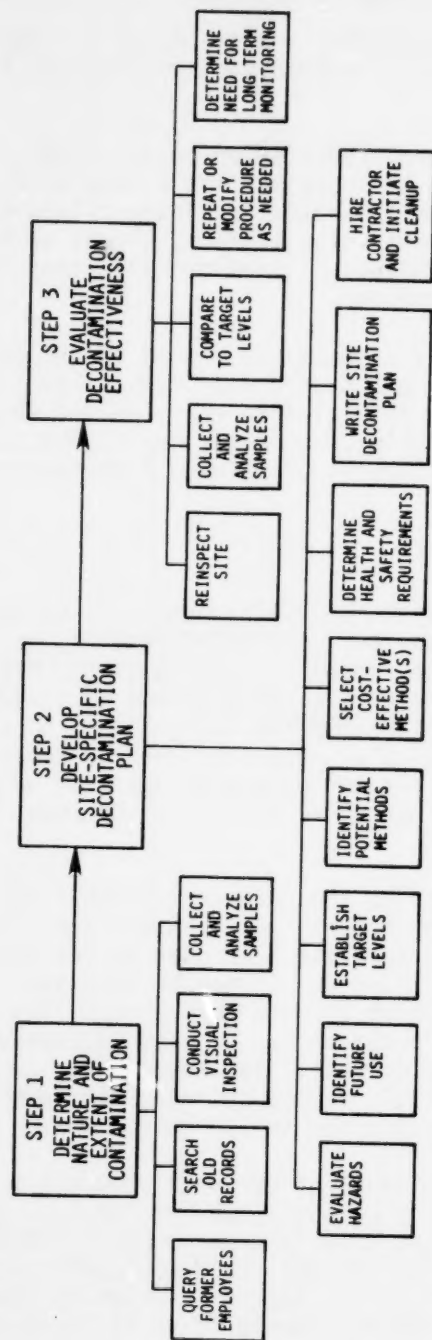


Figure 1. Flow diagram illustrating sequence of steps for developing a decontamination strategy.

Section 3/Nature and Extent of Contamination

an inspection will help determine whether a building or structure has any potential for future use or should be dismantled and disposed of (see Identification of Future Use, p. 9).

During the inspection, rafters, ventilation ducts, sumps, crawl spaces, window wells, tanks, etc., should be inspected for evidence of deterioration as well as chemical residues or contaminated dust/particulate matter. Buildings that are suspected of containing asbestos should be inspected according to EPA-recommended guidelines.³ Similar guidelines for other types of contaminants have not been developed.

Personnel involved in initial inspections should be thoroughly trained in appropriate safety precautions and hazard awareness. Level B protective equipment is commonly used during initial site entry unless the records search indicates that a potential radiation hazard exists or that there may be tanks, cellars, or other closed areas containing high concentrations of toxic gas (see Section 5).

Sampling Survey

Complete characterization of the contamination in or on buildings, structures, and equipment requires that a detailed sampling survey be performed as part of the overall site remedial investigation. Standard sampling techniques can often be used to determine the presence of solid, liquid, or airborne contamination. Methods for sampling and analysis of contaminants in solids and liquids can be found in EPA's Test Methods for Evaluating Solid Wastes (EPA SW-846).⁴ Methods for sampling and analysis of airborne contaminants are contained in the NIOSH Manual of Analytical Methods (Volumes 1 through 7).⁵⁻⁹

Sampling methods for determining the nature and extent of contamination on building and equipment surfaces are not yet standardized. Variations of wet-wipe and dry-wipe techniques that have been used in the field are described in Appendix B. In some instances, it may be necessary to determine the depth of penetration of contaminants into porous materials such as wood, wallboard, or concrete. This information may be used to determine when dismantling or demolition are appropriate. In these cases, small sections of the contaminated structural materials (e.g., corings) should be collected for analysis and handled as a solid waste per SW-846 guidelines.

During sampling, the maximum level of personal protective equipment commensurate with the hazard should be worn (see Section 5). Representative samples should be collected and analyzed in accordance with the quality control guidelines described in the EPA and NIOSH handbooks cited above. Several locations at the site should be sampled in order to identify all contaminated areas. The survey results should identify all contaminated substrates and report contaminant levels by sampling location.

STEP 2. DEVELOPMENT OF A SITE-SPECIFIC DECONTAMINATION PLAN

Once contaminants have been identified, a decontamination plan tailored to the site characteristics can be developed.

Hazard Evaluation

Hazard evaluation is a decision-making process in which the benefits and risks associated with not treating the contaminated buildings, structures, or equipment (i.e., the "do nothing" alternative) are weighed against the potential benefits and risks of decontamination. Two types of hazards need to be evaluated: those associated with the contaminants themselves, and those associated with the cleanup process.

Evaluating the hazards associated with exposure to the contaminants present is important in developing proper handling procedures and safety controls. This hazard evaluation consists of gathering information on the physical and chemical properties of the contaminants, the fire and explosion hazards, the toxicity and health hazards, and chemical reactivity. Physical and chemical properties (e.g., vapor pressure, boiling point, and solubility) may be obtained from standard chemical reference texts. The National Fire Protection Association publishes information on the flammability of approximately 1500 substances.¹⁰ Information on chemical toxicity is available from the National Institute for Occupational Safety and Health (NIOSH) in two data collections that are published annually.^{11,12} Data on the toxic effects from known doses of hazardous substances entering the body are available in NIOSH Criteria Documents¹³ and also from the American Conference of Governmental Industrial Hygienists (ACGIH).¹⁴

All existing exposure limits for particular contaminants must be included in the contaminant hazard evaluation. Such exposure limits represent concentrations to which nearly all workers can be repeatedly exposed, day after day, without adverse effect. The OSHA 29 CFR 1910 Subpart Z currently lists exposure limits for approximately 400 substances. The ACGIH annually publishes exposure limits for approximately 800 chemical substances.¹⁵

Health and safety aspects associated with the use of various cleanup techniques or processes must also be considered as part of the overall hazard evaluation. If two methods are judged to be equally effective in removing or treating a particular contaminant, the method that presents lower risks to the workers would be preferable. Sections 4 and 5 contain additional information on the potential hazards associated with various decontamination methods.

Identification of Future Use

Another early step in the development of a site decontamination plan entails identification of the intended or potential future use of contaminated buildings, structures, and equipment. Building and equipment release

Section 3/Site-Specific Decontamination Plan

following decontamination will fall into one of three categories:

- ° Unrestricted/public use
- ° Restricted/industrial use
- ° No future use

In most cases, it will be necessary to develop a decontamination plan geared to meet the intended or potential future use of the site or equipment. Buildings and structures that have no potential for future use will either be dismantled or demolished, or left standing, fenced, and guarded (see the Appendix D case study of Seveso, Italy). In such cases, a decontamination plan can often be developed that will both reduce the costs of disposal (contaminated debris often must be disposed of in a secure landfill whereas decontaminated debris can be sent to a less costly sanitary landfill) and reduce potential exposure hazards to demolition workers, waste transportation and disposal employees, and the general public.

Although the level of intended reuse generally dictates the extent of contamination reduction required, the planner must be aware that the state-of-the-art decontamination technology is not well advanced. Thus, in some cases, the level of reuse will be limited by the degree of contaminant reduction that can be achieved.

All future owners of decontaminated buildings and structures on Superfund sites should be advised of the nature of the contamination that was present, the cleanup methods used, and levels of any residual contaminants. Ensuring the transfer of such information from one site owner to the next will require a method for permanently recording this information, e.g. by including a notice in the deed to the property (or some other instrument that is normally examined during title search). Federal regulations promulgated by EPA under the Resource Conservation and Recovery Act (RCRA) require such a notice for land that has been used to manage hazardous wastes (40 CFR §264.120).

Establishment of Target Levels

When a future use has been identified, decontamination target levels for all contaminants present should be established. This has been a major obstacle to decontamination activities at Superfund sites. Target levels have been, and can be, set by a number of groups, including local and state health departments and Federal agencies such as EPA, NIOSH, the Occupational Safety and Health Administration (OSHA), the Nuclear Regulatory Commission (NRC), the Centers for Disease Control (CDC), and the Surgeon General's Office. Target levels for Army-unique materials (i.e., explosives) are proposed by the U.S. Army Toxic and Hazardous Materials Agency (USATHAMA), and approved by the Army Surgeon General.

Target levels generally should be more stringent in cases where the buildings, structures, or equipment are to be released for unrestricted/public use as opposed to restricted/industrial use. The EPA has not prescribed levels of contaminants that are acceptable at all Superfund sites; one reason for this is that potential synergistic effects of combinations of wastes cannot be adequately predicted.¹⁶ The Agency is currently preparing draft guidance on the issue of "How clean is clean?"¹

Determination of Potential Cleanup Methods

Determining the most appropriate cleanup method or combination/sequence of methods to be used on buildings, structures, and equipment is central to the development of a decontamination plan. The matrix presented in Table 1 was prepared to assist in the identification of potential cleanup methods. This matrix shows the applicability of several decontamination methods in relation to contaminants and structural materials. Each cell in the matrix represents a specific contaminant/structural material combination and contains numbers corresponding to decontamination methods that would be practical in that application. Each method can be used alone or possibly in conjunction with one or more of the other procedures listed in that cell to improve the effectiveness of the decontamination project.

To illustrate how the matrix works, assume that sampling and analysis of a concrete surface revealed the presence of dioxin contamination. In the cell representing the intersection of the column headed "Concrete" and the row labeled "Dioxin," 15 potential cleanup methods applicable to dioxin-contaminated concrete surfaces are indicated: Methods 2, 3, 5, 6, 7, 9, 10, 11, 12, 13, 14, 18, 19, 20, and 21. The methods are identified using the key at the bottom of the table. Method descriptions are presented in Section 4. The key words at the top of each page can be used to locate the descriptions easily. Each description indicates whether that technique has actually been used to treat a particular contaminant/structural material combination, or whether the method is viewed as potentially applicable.

Evaluation of Decontamination Methods

The decontamination methods indicated in Table 1 for a particular contaminant/structural material combination should be evaluated as part of the site feasibility study. Each technique should be judged on effectiveness, equipment and support facilities needed, time and safety requirements, wastes generated, structural damage, and costs. For example, the hydroblast/waterwash method is a relatively inexpensive surface decontamination technique that utilizes off-the-shelf equipment; however, it produces large amounts of liquid residues that have to be collected and treated. Limitations in manual dexterity and productivity imposed by the use of personal protective gear should be included in the evaluation of potential methods. The method descriptions presented in Section 4 will assist the reader in evaluating all applicable techniques.

TABLE 1. EXAMPLES OF PRACTICAL DECONTAMINATION METHODS FOR VARIOUS CONTAMINANTS AND STRUCTURAL MATERIALS^a

Contaminant	Material						Equipment and auxiliary structures
	Brick	Concrete	Glass	Metal	Plastic	Wood	
Asbestos	1,3,4,5,6	1,3,5,6	1,3,4,5,6	1,3,4,5,6	1,3,4,5,6	1,3,4,5,6	1,3,4,5,6
Acids	2,3,4,6,7,8,9,13	2,3,6,7,8,9,10,13,18	2,3,4,6,9,13	2,3,4,6,7,8,9,13	2,3,4,6,9,13	2,3,4,6,7,9,13	2,3,4,6,7,8,9,13
Alkalis	2,3,4,6,7,8,9,13,15	2,3,6,7,8,9,10,13,15,18	2,3,4,6,9,13,15	2,3,4,6,7,8,9,13,15	2,3,4,6,9,13	2,3,4,6,7,9,13,15	2,3,4,6,7,8,9,13,15
Dioxins	2,3,4,5,6,7,9,11,12,13,14,19,20,21	2,3,5,6,7,9,10,11,12,13,14,18,19,20,21	2,3,4,5,6,9,11,12,13,14,20,21	2,3,4,5,6,9,11,12,13,14,20,21	2,3,4,5,6,9,11,12,13,14,20,21	2,3,4,5,6,9,11,12,13,14,19,20,21	2,3,4,5,6,7,8,9,11,12,13,14,20,21
Explosives	2,3,4,6,7,8,9,11,12,13,14,17	2,3,6,7,8,9,10,11,12,13,14,17,18	2,3,4,6,11,12,13,14	2,3,4,6,7,8,9,11,12,13,14,17	2,3,4,6,9,11,12,13,14	2,3,4,6,7,9,11,12,13,14	2,3,4,6,7,8,9,11,12,13,14,17
Heavy metals and cyanide	2,3,4,5,6,7,8,9,12,13,14,15,19	2,3,5,6,7,8,9,10,12,13,14,15,18,19	2,3,4,5,6,12,13,14,15	2,3,4,5,6,7,8,9,12,13,14,15	2,3,4,5,6,9,12,13,14	2,3,4,5,6,7,9,12,13,14,15,19	2,3,4,5,6,7,8,9,12,13,14,15
Low-level radiation	2,3,4,6,7,8,9,11,12,13,14,17	2,3,6,7,8,9,10,11,12,13,14,17,18	2,3,4,5,6,11,12,13,14	2,3,4,6,7,8,9,11,12,13,14,17	2,3,4,6,9,11,12,13,14	2,3,4,6,7,9,11,12,13,14	2,3,4,6,7,8,9,11,12,13,14,17
Organic solvents	2,3,4,6,7,8,9,11,12,13,14,20,21	2,3,6,7,8,9,10,11,12,13,14,18,20,21	2,3,4,6,9,11,12,13,14,20,21	2,3,4,6,7,8,9,11,12,13,14,20,21	2,3,4,6,9,11,12,13,14,20,21	2,3,4,6,7,9,11,12,13,14,20,21	2,3,4,6,7,8,9,11,12,13,14,20,21
Pesticides	2,3,4,5,6,7,8,9,11,12,13,14,16,19,20,21	2,3,5,6,7,8,9,10,11,12,13,14,16,18,19,20,21	2,3,4,5,6,9,11,12,13,14,20,21	2,3,4,5,6,7,8,9,11,12,13,14,16,20,21	2,3,4,5,6,9,11,12,13,14,20,21	2,3,4,5,6,7,9,11,12,13,14,16,19,20,21	2,3,4,5,6,7,8,9,11,12,13,14,16,20,21
PCB's	2,3,4,5,6,7,8,9,11,12,13,14,19,20,21	2,3,5,6,7,8,9,10,11,12,13,14,18,19,20,21	2,3,4,5,6,11,12,13,14,20,21	2,3,4,5,6,7,8,9,11,12,13,14,20,21	2,3,4,5,6,9,11,12,13,14,20,21	2,3,4,5,6,7,9,11,12,13,14,19,20,21	2,3,4,5,6,7,8,9,11,12,13,14,20,21

Key for decontamination methods:

- | | | |
|--|------------------------------------|--|
| 1. Asbestos abatement | 8. Hydroblasting/waterwashing | 15. Acid etching |
| 2. Absorption ^b | 9. Painting/coating | 16. Bleaching |
| 3. Demolition ^c | 10. Scarification ^{e,f} | 17. Flaming |
| 4. Dismantling | 11. RadKleen | 18. Drilling and spalling ^{e,f} |
| 5. Dusting/vacuuming/wiping ^d | 12. Solvent washing | 19. K-20 sealant |
| 6. Encapsulation | 13. Steam cleaning | 20. Microbial degradation |
| 7. Gritblasting ^e | 14. Vapor-phase solvent extraction | 21. Photochemical degradation |

^a Refer to individual method descriptions in Section 4 to determine whether an indicated technique has actually been used to treat a particular contaminant/structural material combination, or whether the method is viewed as potentially applicable.

^b Applicable only to liquids.

^c Some contaminant residues (e.g., asbestos, explosives, toxic residues) may have to be neutralized, stabilized, or removed prior to demolition to prevent explosions or emissions.

^d Applicable only to particulates and solids.

^e Not recommended for removing highly toxic residues or highly sensitive explosives, unless particulates can be controlled.

^f Applicable only to concrete.

Selection of the Most Appropriate Method(s)

Based on the requirements of the National Contingency Plan, the decontamination method(s) of choice in a Superfund-financed cleanup should always be the least-costly, technologically feasible alternative that can reduce the contamination to predetermined levels. This philosophy was demonstrated at the Sontag Road Area Superfund site (Appendix F), where dusting/vacuuming/wiping techniques were chosen over painting and coating methods because of cost considerations.

Determination of Worker Health and Safety Requirements

The hazard evaluation data developed earlier should be used to determine the worker health and safety precautions required during decontamination operations. Personnel training, medical surveillance, personal protective equipment, and site safety are covered in Section 5.

Preparation of Site Decontamination Plan

Before cleanup is initiated, a detailed site decontamination plan should be written and incorporated into the remedial design specifications. This plan should specify the decontamination method to be implemented, the QA/QC procedures to be followed, the equipment and support facilities needed, the method of residue disposal, worker health and safety precautions, and scheduling.

Initiation of Cleanup

Following approval of the decontamination plan by EPA headquarters, a contractor(s) can be hired to initiate cleanup. Decontamination should proceed according to plan. Contaminant levels should be monitored throughout the course of the operation so that decontamination effectiveness can be evaluated.

STEP 3. EVALUATION OF DECONTAMINATION EFFECTIVENESS

The extent of residual contamination following decontamination must be determined so the effectiveness of the cleanup methods can be assessed. A visual inspection and detailed sampling survey should be conducted in the same manner as described previously. The results of this survey should then be compared with the decontamination target levels. If the target levels have not been reached, the decontamination procedure or sequence must be repeated or amended as necessary. Once target levels have been achieved, the need for long-term monitoring to provide assurances that the target levels will be maintained should be considered. This is especially important in situations where contaminants have not been removed but have been left in place behind protective coatings or barriers.

Section 3/Case Studies

CASE STUDIES

Appendices D through K present case studies illustrating decontamination strategies that have been implemented at both Superfund and non-Superfund sites. The summary of these case studies, presented in Table 2, lists the contaminants present and the decontamination methods used at each site. Limited factual data are available on the concentrations of contaminants present and the degree of decontamination achieved following cleanup. This is reflective of the inadequacies in the techniques used to sample and analyze for hazardous constituents on building and equipment surfaces.

TABLE 2. SUMMARY OF CASE STUDIES

Appendix	Site	Contaminants present	Decontamination methods
D	Homes and other buildings Seveso, Italy	TCDD	Dusting/vacuuming/wiping Painting/coating Dismantling Demolition
E	State Office Building Binghamton, New York	PCB's, TCDD, TCDF	Dusting/vacuuming/wiping Dismantling
F	Sontag Road area ^a St. Louis County, Missouri	TCDD	Dusting/vacuuming/wiping Insulation removal Scrubbing (equipment only) Steam cleaning (equipment only)
G	One Market Plaza Office Complex San Francisco, California	PCB's, PCDD, PCDF	Insulation removal Dusting/vacuuming/wiping Solvent washing Scraping Painting/coating K-20 Gritblasting Scarification/jackhammering Dismantling Hydroblasting/waterwashing (equipment only)
H	Frankford Arsenal Philadelphia, Pennsylvania	Explosives	Flaming Demolition
		Asbestos	Asbestos removal
		Radiological residues	Dusting/vacuuming/wiping Hydroblasting/waterwashing Scarification Gritblasting Dismantling
		Heavy metals	Painting/coating
I	Office building New England	Asbestos	Asbestos encapsulation
J	Luminous Processes, Inc. ^a Athens, Georgia	Low-level radiation	Paint stripping/sanding Hydroblasting/waterwashing Dismantling
K	Chemical Metals Industries, Inc. Baltimore, Maryland	Heavy metals, acids, alkalis, cyanide- and ammonia-bearing compounds, salts, and solids and sludges of unknown composition	Gritblasting Dismantling

^a Superfund site.

SECTION 4

DECONTAMINATION METHODS

The matrix introduced in Section 3 (Table 1) identified several methods (established and potential) for decontaminating various combinations of contaminants and structural materials encountered at Superfund sites. More detailed descriptions of those methods are presented in this section. Using this information, the reader should be able to assess each method for its applicability to the decontamination requirements of a specific site.

The methods presented range from classical techniques to developmental concepts. For example, abrasive gritblasting and vacuuming are traditional procedures whose applications have been extended to the cleanup of hazardous waste sites. At the other end of the spectrum are methods that are in developmental stages, such as the drill-and-spill procedure. The developmental methods included here either have been applied in at least one demonstration or have shown the likelihood of being useful techniques. Use of these techniques in concert with, or in place of, the more classical techniques should be considered when developing a decontamination strategy.

Table 3 summarizes the advantages and disadvantages of the decontamination methods presented in this section. Method descriptions include a general discussion of the procedure, advantages, disadvantages, state of the art, applicability, effectiveness, engineering considerations (including building preparation, process description, equipment needs, and time requirements), safety requirements, waste disposal, costs, future work required, and information sources. Comparative cost information developed for each of the methods is further detailed in Appendix C.

ASBESTOS ABATEMENT (METHOD 1)

Four techniques are available for the abatement of asbestos contamination in buildings: removal, encapsulation, enclosure, and special operations (e.g., maintenance and monitoring). Each technique is discussed separately.

TABLE 3. SUMMARY OF THE ADVANTAGES AND DISADVANTAGES OF VARIOUS DECONTAMINATION METHODS^a

Method	Advantages	Disadvantages
1. Asbestos abatement a) Removal	Permanently eliminates the source of asbestos fibers.	Is costly and time-consuming if complex surfaces (pipes, ducts, crevices, etc.) are involved; may require sealing of porous surfaces after removal.
b) Encapsulation	Initially, may be lower in cost than removal; does not require replacement of the asbestos-containing material.	May be more costly than removal over the long term because periodic reinspections are required to check for damage and deterioration and because subsequent repair of the encapsulated surface may be necessary; can affect (i.e., reduce) the fireproofing properties of the asbestos-containing materials; may make the eventual removal of asbestos-containing materials more difficult.
c) Enclosure	Initially, may be lower in cost than removal.	May be more costly than removal over the long term because periodic reinspections are required to check for damage and because subsequent repair of the damage may be necessary; requires controlled access for maintenance or renovation activities; requires eventual removal of the asbestos source, particularly prior to building renovation or demolition.
d) Special operations	Initially, may be lower in cost than removal.	Applies only to nonfriable asbestos. Requires periodic reinspection of the asbestos-containing materials and other future control measures.
2. Absorption	Quickly contains gross contamination.	Normally requires secondary decontamination to clean up surface residues and subsurface contamination.
3. Demolition	Achieves total decontamination by removing all contaminated building materials, structures, and equipment from the site.	Completely destroys the building, structure, or equipment; generates large quantities of contaminated debris for disposal; may expose workers or nearby residents to airborne contamination.

(continued)

Table 3 (continued)

Method	Advantages	Disadvantages
4. Dismantling	Is less costly than complete demolition because only those structures that are contaminated are removed.	Generates large quantities of contaminated debris for disposal.
5. Dusting/vacuuming/wiping	Generates small volumes of waste/wastewater, which are contained and easily disposed of in vacuum cleaner bags or on wipe cloths.	May spread contamination by creating fugitive dusts; may have to be repeated until the source of contamination is controlled.
6. Encapsulation/enclosure	Does not create large volumes of contaminated debris.	May render structures inaccessible or inoperable.
7. Gritblasting	Can simultaneously and readily remove paint and contaminants near the surface.	Generates large amounts of dust and debris; is slow, and effective only as a surface treatment; has the potential for detonating pockets of combustible contaminants.
8. Hydroblasting/waterwashing	Offers a relatively inexpensive, nonhazardous surface decontamination technique that uses off-the-shelf equipment; can very easily incorporate variations such as hot or cold water, abrasives, solvents, surfactants, and varied pressures.	May not effectively remove contaminants that have penetrated the surface layer; requires collection and treatment of large amounts of contaminated liquids.
9. Painting/coating a) Lead-based paint removal b) Fixative/stabilizer coatings c) Strippable coatings	Does not require large investments in equipment. Reduces the level of contamination to which building occupants are exposed; does not create any hazardous wastes. Physically holds or traps the contaminant for easier handling and disposal.	Involves labor-intensive operations that cannot be automated. Does not remove toxic contaminants; requires lifetime monitoring of the effectiveness of the barrier coating. May bind to the surface of the wall or item on which it is applied, resulting in large volumes of wastes or damage to the surface.
10. Scarification	Can achieve a deeper penetration (removal) than most other surface removal techniques; is suitable for application to both large open areas and small areas.	Requires resurfacing of the treated surface; generates contaminant-laden dust and substantial amounts of contaminated debris (water and concrete) that require further processing; presents a potential explosion hazard if pockets of combustible wastes are encountered; is restricted to use on concrete or concrete-like materials; can only be used in obstruction-free areas.

(continued)

Table 3 (continued)

Method	Advantages	Disadvantages
11. RedKleen	Uses Freon 113 (a stable, nonpolar, noncombustible organic solvent), which permits rapid wetting of surfaces and easy particulate separation; allows for solvent recovery if used in a closed system.	Requires secondary treatment of the used Freon.
12. Solvent washing	Can remove contaminated paint if the proper solvent is selected.	Is not suitable for intricate structures; may tend to carry contaminants farther into the wall before outward movement occurs; may require removal and/or decomposition of residual solvent in building materials.
13. Steam cleaning	Is relatively inexpensive and simple; depending on the contaminant, may cause thermal decomposition and/or hydrolysis to occur.	Is known to be effective only for surface decontamination; is labor-intensive and costly if automated; generates large volumes of contaminated water.
14. Vapor-phase solvent extraction	Enhances solvent permeability and diffusibility; is well suited to all areas of a building, including intricate structures; can remove contaminated paint if the proper solvent is selected.	May require long treatment times for outward diffusion of contaminant-laden solvent.
15. Acid etching	Certain contaminants are decomposed as they are removed from the surface.	Requires a large volume of acid (hazardous) and special application equipment; is applicable only to metals that will readily corrode.
16. Bleaching	Is an effective decontaminating agent when used against metal surfaces.	Depending on the concentration and composition of the bleach slurry, may cause corrosion of application equipment and/or the surfaces being treated; may also cause periodic clogging of application equipment.
17. Flaming	Provides complete and rapid destruction of all residues contacted.	Is primarily a surface decontamination technique; would probably result in extensive damage to the material if used for subsurface decontamination; may detonate combustible residues; can involve high fuel costs.

(continued)

Table 3 (continued)

Method	Advantages	Disadvantages
18. Drilling and spalling	Can achieve deeper penetration (removal) of surfaces than other surface-removal techniques; is good for large-scale application.	Requires resurfacing of the treated surface; may expose rebar; generates substantial amounts of contaminated debris.
19. K-20 sealant	Immobilizes contaminants in situ; does not generate hazardous wastes.	Is in the developmental stages; has not yet gained Federal approval for widespread use.
20. Microbial degradation	Is specific to targeted contaminants.	Requires a large development effort to achieve a workable system; would probably require supplementary treatment; may give rise to biological degradation products containing carcinogenic compounds.
21. Photochemical degradation	Can be relatively simple or scaled-up (accompanied by increased technical efforts); is inexpensive when sunlight is used as the UV light source.	Will not work on contaminants imbedded in dense particulate matter (such as thick carpet or deep soil) because UV light cannot penetrate through these surfaces; may result in exposure hazards from the use of intense UV radiation sources other than the sun (mercury and xenon-arc lamps) and from the use of flammable solvents as hydrogen donors.

^a The methods described in this table are examples of techniques currently available. The list is not exhaustive; other methods may be available.

Section 4/Asbestos Removal (Method 1A)

ASBESTOS REMOVAL (METHOD 1A)

General Description

Asbestos-containing building materials are removed to prevent the release of asbestos fibers into the air. Replacement of the removed material with a nonasbestos material may be necessary to comply with building or fire codes.

Advantages

Removal permanently eliminates the source of asbestos fibers.

Disadvantages

If removal from complex surfaces (pipes, ducts, crevices, etc.) is required, this technique may be costly and time-consuming. After removal, porous surfaces may require sealing with a chemical penetrant (see Method 1B). Because improper work practices may increase asbestos fiber levels in air, removal operations must be carefully planned and closely supervised.

State of the Art

Removal has been used in many buildings (schools, public, and commercial buildings) where friable (easily crumbled) asbestos-containing materials posed a potential health hazard to building occupants.

Variations of Idea

Unless the asbestos-containing material is damaged, deteriorating, or exposed, fiber release may be controlled by other methods such as enclosure, encapsulation, or special operations.

Applicability

Removal eliminates the source of asbestos and precludes the development of future problems. It is especially suitable for damaged and deteriorating asbestos-containing materials.

Effectiveness

Complete removal of asbestos-containing insulation from the area eliminates the asbestos hazard.

Engineering Considerations

Building Preparation--

Prior to the removal (or disturbance) of asbestos-containing materials, the work area is isolated so that all asbestos fibers released by the removal activity will be confined to the work area. Temporary partitions are constructed, and all exposed surfaces (other than those that are being removed)

are covered with plastic sheeting. Ventilation to and from the work area is sealed off. High-efficiency particulate air (HEPA) filtration of the work area air is desirable to afford stringent control of fiber levels and to minimize the risk of asbestos exposure to removal workers and/or building occupants (if the building remains occupied during removal). To do this, powered exhaust equipment is used to exhaust air from the work area through a high-efficiency filter (defined as a filter that is at least 99.9 percent efficient in collecting particles with aerodynamic diameters of 0.3 μ m) to the environment outside the building.

Process Description--

After the work area has been enclosed and plastic sheeting placed over all exposed surfaces, the asbestos-containing material is wetted in place with amended water*. While still wet, the material is physically removed and placed in sealable bags or containers. When removal is complete, the work area is subjected to a thorough cleaning. All surfaces are wet-wiped or mopped. Vacuums equipped with high-efficiency filters may be used to vacuum up any visible debris deposited on building floors, ledges, other equipment, etc. Porous surfaces may require sealing with a chemical penetrant to prevent the release of any residual fibers (see Method 1B).

For prevention of possible spread of fibers, equipment and persons leaving the work area must pass through a partitioned area designated as the decontamination chamber. In this chamber, equipment is wet-wiped to remove asbestos contamination, and used protective clothing is discarded into sealable containers to be disposed of later as asbestos-containing waste. A portable shower and a change area may be provided for the use of workers exiting the work area. Spent shower water is filtered with a high-efficiency filter that is later disposed of as asbestos-containing waste.

A visual inspection is conducted following removal of the asbestos-containing material to detect incomplete work or inadequate cleanup. Following a satisfactory visual inspection, the work area remains undisturbed for 24 to 72 h to allow time for fibers to settle. Air monitoring is then conducted to measure the level of residual asbestos fibers according to the NIOSH method for asbestos fibers in air (Method No. P & CAM 239, 1977).⁵ When air monitoring results indicate that the work area is adequately decontaminated of asbestos, the isolation barriers are disassembled, placed in sealable containers, and later disposed of in approved landfills. The removed asbestos-containing material may be replaced with a nonasbestos substitute to comply with building or fire codes.

Equipment and Support Facilities Needed--

The following equipment is needed: temporary partitions and plastic sheeting; water sprayer; shears and scraping tools; sealable bags and containers; portable HEPA-filtration devices, such as the Micro-Trap (Asbestos Control Technology, Inc., New Jersey) or the Air Tech 2000 (Industrial Safety

* Water with surfactant added to increase wetting action.

Section 4/Asbestos Removal (Method 1A)

Products, Inc.); HEPA-filter-equipped vacuums, such as those manufactured by Nilfisk of America, Inc., or the Minuteman Asbestos Vacuum Model 80315 by Minuteman, Inc.; Level C protective equipment including full-body protective coveralls and NIOSH/MSHA-approved respirators; and air monitoring equipment. In addition, major abatement jobs will require a shower area and change room.

Time Requirements--

Approximately 30 percent of the total time necessary to remove asbestos-containing material involves preparation of the work area. Actual time depends upon the size and complexity of the removal task.

Personnel time requirements depend upon the amount of material removed, and whether a nonasbestos replacement material is installed.

Approximately the same time is required for tear-down as that for preparation of the work area. More time may be required if final air tests are unsatisfactory and the work area must be recleaned.

Safety Requirements

Potential hazards to personnel include inhalation of asbestos fibers (known to be fibrogenic and carcinogenic); electrical shock from the use of water (for wetting) in proximity to electrical equipment; and heat stress caused by high temperatures and humidity, no or minimal ventilation, and the full protective clothing worn by workers.

The release of fibers should be controlled by wetting all asbestos-containing material prior to its removal (EPA regulation 40 CFR 61). Workers must wear NIOSH/MSHA-approved respirators (selected from among those approved under the provisions of 30 CFR Part 11, 37 F.R. 6244, March 25, 1972) and full-body protective coveralls while in the work area. Major abatement projects will require a portable shower room and a secure change area (for changing from protective clothing to street clothes).

Work areas where asbestos fibers are released must be monitored to evaluate workers' exposures to asbestos fibers compared with the exposure limits prescribed in OSHA regulation 29 CFR 1910.1001, paragraph (b). Sampling equipment and methods are described fully in 1919.1001, paragraphs (e) and (f), and in the NIOSH method for asbestos fibers in air (Method No. P & CAM 239, 1977).⁵ Air samples should be taken during actual removal of the asbestos-containing material and after removal has been completed. See Section 5 for additional worker health and safety requirements.

Waste Disposal

All asbestos-containing waste must be sealed into impermeable bags or containers. These containers are labeled in accordance with OSHA regulation 29 CFR 1910.1001 and disposed of in approved landfills in accordance with EPA regulation 40 CFR 61.25.

Costs

Structural Damage and Repair Costs--

Physical damage to the building should be minimal. Wet removal with inadequate floor protection may cause warping of wooden floors. Disassembling the containment barriers may cause wall or ceiling paint to crack or peel.

Treatment and Disposal Costs--

Costs for utilities and fuel should be low. Equipment and disposal costs should be moderate. Personnel costs should be moderate to high; removal of asbestos-containing material is generally the most labor-intensive asbestos-abatement technique. Hourly wages for asbestos workers range from approximately \$17 to \$25 (1983 dollars).¹⁷ See the cost analysis in Appendix C for additional information.

Information Sources

The bulk of the information in this subsection came from References 3 and 18. Use of this method is illustrated in the case study presented in Appendix H.

ASBESTOS ENCAPSULATION (METHOD 1B)

General Description

A chemical penetrant or bridging-type sealant is spray-applied to asbestos-containing materials to bind together asbestos fibers and other material components for reduction of asbestos fiber release into the air.

Advantages

The initial cost of encapsulation may be lower than that of asbestos removal. Also, the asbestos-containing material does not need to be replaced.

Disadvantages

Because periodic reinspections are required to check for damage or deterioration and because subsequent repair of the encapsulated surface may be necessary, the long-term costs of encapsulation may be higher than the cost of asbestos removal. Encapsulating agents can affect (i.e., reduce) the fire-proofing properties of the asbestos-containing materials. In addition, encapsulation of asbestos-containing material makes their eventual removal more difficult.

Section 4/Asbestos Encapsulation (Method 1B)

State of the Art

Encapsulants are, at best, a temporary control measure. Control effectiveness depends partially on the correct choice of encapsulant. Encapsulants are evaluated according to adhesive/cohesive strength, ability to adhere to substrate, impact resistance, and toxicity.

Variations of Idea

If the asbestos-containing material is in poor condition or easily accessible, other methods of asbestos hazard abatement (e.g., removal or enclosure) should be used.

Applicability

Encapsulation is only appropriate for asbestos-containing materials that are in good condition, that have excellent adhesive and cohesive properties, and that are not highly accessible. Asbestos-containing pipe insulation should not be encapsulated. Pipe lagging discourages the encapsulant's penetration into the asbestos-containing material and reduces binding of the asbestos fibers and other material components.

Effectiveness

Encapsulation satisfactorily controls release of asbestos fibers as long as the treated asbestos-containing materials remain in good condition, are free from water damage, and are not subject to physical contact.

Engineering Considerations

Building Preparation--

Encapsulants are usually spray-applied. This contact disturbance has the potential for releasing asbestos fibers. Thus, prior to encapsulation, the entire work area must be isolated so that all asbestos fibers are confined to this area. Ventilation to and from the work area should be shut off. Once encapsulation work begins, high-efficiency filtration of the work area air is desirable for stringent control of fiber levels (see Method 1A).

Process Description--

After the work area has been isolated with temporary partitions and plastic sheet barriers, all surfaces except the material to be encapsulated are covered with plastic sheeting. The sealant is spray-applied with very low nozzle pressure to minimize contact disturbance. After the encapsulant is allowed to dry, a second coat may be applied. The work area is then inspected for completeness of the work.

To prevent the possible spread of asbestos fibers, equipment and persons leaving the work area should pass through a decontamination chamber as described in Method 1A.

Section 4/Asbestos Encapsulation (Method 1B)

Before the containment barriers are disassembled, the work area must be thoroughly cleaned. All surfaces are wet-wiped or mopped. Vacuums equipped with high-efficiency filters may be used to vacuum up any visible debris deposited on floors, ledges, other equipment, etc. The plastic sheeting used as isolation barriers is rolled up and placed in sealable containers and later disposed of as asbestos-contaminated waste.

Equipment and Support Facilities Needed--

Temporary partitions and plastic sheeting, encapsulants, spray application equipment, sealable bags and containers, HEPA-equipped vacuums, Level C protective gear, and air monitoring equipment are required.

Time Requirements--

The time necessary to construct containment barriers and cover exposed surfaces is the same as for Method 1A. If the area is complex (i.e., difficult corners or areas with difficult access), more time will be required.

Spray application proceeds fairly rapidly. Encapsulant drying time may require from several hours to one or two days, especially if more than one coat is necessary.

Tear-down time should be minimal.

Safety Requirements

Potential hazards to personnel include inhalation of asbestos fibers; inhalation of toxic vapors from sealants; and heat stress caused by high temperatures and humidity, no or minimal ventilation, and the full protective clothing worn by workers. Workers should wear NIOSH/MSHA respirators approved under 30 CFR Part 11 for asbestos and any toxic vapors that may be present in the encapsulant. Full-body protective coveralls should be worn.

Work areas where asbestos fibers are released must be monitored to evaluate workers' exposures to asbestos fibers against the exposure limits prescribed in OSHA regulation 29 CFR 1910.1001, paragraph (b). Sampling equipment and methods are described fully in 1910.1001, paragraphs (e) and (f), and in the NIOSH method for asbestos fibers in air (Method No. P & CAM 239, 1977).⁵ Air samples should be taken during and after encapsulation. See Section 5 for additional worker health and safety requirements.

Waste Disposal

The plastic barriers used to contain the work area during encapsulation are treated as asbestos-contaminated waste. All asbestos-contaminated waste is sealed into impermeable bags or containers, labeled in accordance with OSHA regulation 29 CFR 1910.1001, and disposed of in landfills in accordance with EPA regulation 40 CFR 61.25.

Section 4/Asbestos Enclosure (Method 1C)

Costs

Structural Damage and Repair Costs--

Building damage and repair costs should be minimal.

Treatment and Disposal Costs--

Costs for utilities and fuel should be low. Equipment costs should be moderate; encapsulants and special airless sprayers will have to be purchased. Labor costs should be moderate. Waste disposal costs should be low. See the cost analysis in Appendix C for additional information.

Information Sources

The bulk of the information in this subsection came from References 3 and 18. Use of this method is illustrated in the case study presented in Appendix I.

ASBESTOS ENCLOSURE (METHOD 1C)

General Description

A permanent barrier is erected between the asbestos-containing material and all portions of the occupied building. Release of asbestos fibers is contained behind the barrier.

Advantages

The initial cost of enclosure may be lower than that of asbestos removal.

Disadvantages

Long-term costs may be higher than the costs of asbestos removal because of the required periodic reinspections of the enclosure to check for damage and the repair of any damage found. Access to the enclosure for maintenance or renovation activities will need to be controlled through a special operations program. The asbestos source remains and must be removed later (particularly prior to building renovation or demolition).

State of the Art

Properly constructed and maintained enclosures can prevent emission of fibers to other building areas for the remaining life of the building.

Variations of Idea

If the asbestos-containing materials are in areas where frequent entry or activity occurs or if these materials are damaged and deteriorating, enclosure is not a suitable control technique, and complete removal should be considered to abate the asbestos hazard.

Applicability

Enclosure is a suitable asbestos-hazard-abatement technique, particularly when the asbestos-containing materials are located in building areas where entry or disturbance is unlikely. Enclosure isolates asbestos-containing materials from building occupants. For example, enclosing asbestos-insulated steam pipes located in a busy corridor protects occupants from that asbestos source.

Effectiveness

Release of asbestos fibers is contained behind the barrier so that potential exposures outside the enclosure are reduced. Fiber release continues behind the enclosure.

Engineering Considerations

Building Preparation--

During construction of an enclosure, asbestos fiber release is likely to occur. Therefore, containment barriers should be constructed to isolate the work area from the rest of the building. Ventilation to and from the work area should be shut off. Once enclosure work begins, high-efficiency filtration of the work area air is desirable for stringent control of fiber levels (see Method 1A).

Process Description--

After the work area is isolated with temporary partitions and plastic sheet barriers, an enclosure is constructed around the asbestos-containing material so that it is totally contained within the enclosure. Examples of enclosure construction include gypsum panels taped at the seams, tongue and groove boards, and boards with spline joints. Lighting fixtures, plumbing lines, and electrical cables may have to be relocated.

To prevent the possible spread of fibers, equipment and persons leaving the work area should pass through a decontamination chamber as described in Method 1A.

Before the containment barriers are disassembled, the work area must be thoroughly cleaned. All surfaces are wet-wiped or mopped. Vacuums equipped with high-efficiency filters may be used to vacuum up any visible debris

Section 4/Asbestos Enclosure (Method 1C)

deposited on floors, ledges, other equipment, etc. The plastic sheeting used as isolation barriers is rolled up and placed in sealable containers and later disposed of as asbestos-contaminated waste.

Equipment and Support Facilities Needed--

Equipment requirements include enclosure construction materials, sealable bags and containers, HEPA-equipped vacuums, Level C protective gear, and air monitoring equipment.

Time Requirements--

Work area preparation time should be the same as that required for asbestos removal. The time necessary to construct enclosure barriers should be less than that required to remove asbestos. Cleanup time is approximately the same for both techniques.

Safety Requirements

Because asbestos fibers are released to the air by the disturbance of asbestos-containing materials during work activity, inhalation of asbestos fibers is a potential hazard. To prevent this, workers should wear NIOSH/MSHA-approved respirators and full-body protective clothing while in the work area. If drilling into asbestos-covered surfaces is required, drills should be equipped with HEPA-filter-equipped vacuums to reduce fiber levels in work area air.

Work areas where asbestos fibers are released must be monitored to evaluate exposures to asbestos fibers with reference to the exposure limits prescribed in OSHA regulation 29 CFR 1910.1001, paragraph (b). Sampling equipment and methods are described fully in 1910.1001, paragraphs (e) and (f), and in the NIOSH method for asbestos fibers in air (Method No. P & CAM 239, 1977).⁵ Air samples should be taken during construction of the enclosure. Worker exposure should also be monitored whenever work is performed behind the enclosure (such as periodic maintenance activity). See Section 5 for additional worker health and safety requirements.

Waste Disposal

Plastic sheeting used to contain the work area during construction of the enclosure is disposed of as asbestos-contaminated waste. Sealed containers of asbestos-contaminated material are disposed of in accordance with EPA regulation 40 CFR 61.25.

Costs

Structural Damage and Repair Costs--

Total costs may be equivalent to those accrued in asbestos removal because periodic inspection and repair of the enclosure will be required for the life of the building. Building utilities may need to be relocated.

Treatment and Disposal Costs--

Costs for utilities, fuel, equipment, labor, and disposal should be minimal.

Information Sources

The bulk of the information in this subsection came from References 3 and 18.

SPECIAL OPERATIONS (METHOD 1D)

General Description

Building cleanup, special maintenance procedures, repair of asbestos-containing materials, and periodic reassessment of the need for other control measures are used to control the potential for asbestos exposure to building occupants.

Advantages

These procedures minimize initial costs, while providing reasonable assurance of protection to building occupants.

Disadvantages

Because the asbestos source remains, other control measures will be required at some future time. Periodic reinspections of the asbestos-containing materials are required.

State of the Art

Special operations have been used in many instances to defer the initial costs of other asbestos abatement control techniques.

Variations of Idea

The asbestos-containing materials may require other control measures, depending upon future reassessments of material condition.

Applicability

Special operations are appropriate when asbestos-containing materials are nonfriable and in good condition, and the potential for disturbance or erosion is low.

Section 4/Special Operations (Method 1D)

Effectiveness

Asbestos fiber release is adequately controlled by special operations as long as the asbestos-containing materials remain in good condition.

Engineering Considerations

Process Description--

Special operations include conducting a thorough building cleanup, repairing damaged asbestos-containing materials, implementing special maintenance procedures, and instituting an ongoing inspection program.

Carpets are steam-cleaned or vacuumed with HEPA-filtered vacuum cleaners. Furniture, floors, equipment, and other exposed surfaces should be vacuumed (HEPA-equipped vacuum) or wet-wiped or mopped with a mild soap solution.

Missing panels in suspended tile ceilings that conceal asbestos-containing materials should be replaced. Open joints or exposed edges on asbestos-containing pipe insulation should be sealed with duct tape.

Special written procedures should be developed for maintenance personnel who must perform work in areas where there is a potential for disturbing asbestos-containing materials. Procedures should designate proper work and cleanup practices and recommend personal protective equipment.

At regular intervals, asbestos-containing materials should be visually inspected. Other control measures, such as removal, encapsulation, and enclosure, should be evaluated for their appropriateness at that time.

Equipment and Support Facilities Needed--

Equipment requirements include wipes, mops, HEPA-equipped vacuums, Level C protective gear, and air monitoring equipment.

Time Requirements--

Initial building cleanup and repair of asbestos-containing materials may take from a few days to a week, depending upon the size of the building. Special maintenance operations and an inspection program are ongoing activities.

Safety Requirements

Personnel hazards may include inhalation of asbestos fibers. Workers should wear respirators approved for use with asbestos fibers when engaged in operations that have the potential for disturbance of asbestos-containing materials. Maintenance employees should be trained in asbestos hazards and proper work practices and precautions.

Maintenance operations that are likely to disturb asbestos-containing materials and cause release of asbestos fibers should be periodically monitored to typify workers' exposures to asbestos fibers during those operations. Exposure limits are prescribed in OSHA regulation 29 CFR 1910.1001, paragraph (b). Sampling equipment and methods are described fully in 1910.1001, paragraphs (e) and (f), and in the NIOSH method for asbestos fibers in air (Method No. P & CAM 239, 1977).⁵ See Section 5 for additional worker health and safety requirements.

Waste Disposal

Few asbestos-contaminated wastes will be generated, but cloths, mops, and filters may need to be treated as hazardous wastes. Asbestos-contaminated materials are disposed of in accordance with EPA regulation 40 CFR 61.25.

Costs

Structural Damage and Repair Costs--

Little or no damage to the building is expected. Repair costs for pipe insulation or suspended ceilings should be minimal.

Treatment and Disposal Costs--

Costs for utilities and fuel should be very low; no unusual utility consumption is involved. Equipment costs should be minimal; purchase of HEPA-equipped vacuums, which range in cost from a few hundred to several thousand dollars, is one possible expense. Labor costs should be minimal; current building maintenance employees may be trained and utilized. Disposal costs should be low.

Information Sources

The bulk of the information in this subsection came from References 3 and 18.

ABSORPTION (METHOD 2)

General Description

Absorbent materials are used to pick up liquid contaminants. This method is most applicable immediately following liquid contaminant spills. Spills rapidly penetrate most surfaces, and absorbents act to contain contaminants and prevent such penetration. Depending on the surface and time elapsed since the spill, further decontamination procedures may have to be employed.

Section 4/Absorption (Method 2)

Advantages

Absorbents act quickly to contain gross contamination.

Disadvantages

Secondary decontamination is normally required to clean up surface residues and subsurface contamination.

State of the Art

Absorbents are widely used in industrial settings to clean up liquid chemical spills. They are also commonly used by emergency response teams such as fire departments to absorb accidental spills on highways and other surfaces.

Variations of Idea

Many different absorbent materials can be used. Among them are attaclay, sand, anhydrous filler, sandy loam soil, and sawdust. If possible, a clay-based material should be used; however, if one is not available, soil and any other immediately available absorbent material should be used.

Applicability

Absorbents can be used to remove liquid contaminants from all surfaces.

Effectiveness

The efficiency of absorbents differs among specific absorbent materials and with the building materials on which they are used. Experimental studies have indicated clay is most efficient followed by anhydrous filler, soils, and sawdust. Greatest recovery of liquid contaminants can be expected from smooth metal surfaces followed by wood or concrete surfaces.

Engineering Considerations

Process Description--

The absorbent application process is fairly simple. As soon as possible following the contaminant spill, the absorbent material is applied to the liquid puddle(s). Application can be by hand, shovel, dump truck, or other mechanical or manual means. After time has been allotted for the absorbents to soak up the contaminated liquid, the contaminated absorbent is removed by shovel or other means and placed in containers for delivery to a disposal site. Depending on the surface and time elapsed since the spill, secondary decontamination may be required to clean up surface residues and subsurface contamination.

Equipment and Support Facilities Needed--

Absorbent materials, application and removal equipment, and Level C personal protective gear are needed. All equipment can be purchased from commercial manufacturers.

Time Requirements--

Decontamination time is relatively short; most absorbents reach removal capacity after 1 or 2 h.

Safety Requirements

Basic safety requirements applicable to hazardous waste spills should be followed. All possible sources of ignition must be eliminated from areas containing spills of volatile, flammable liquids. Gloves, coveralls, safety glasses, suitable respiratory protection, and boots should be worn in all cases. The need for additional safety equipment and procedures will depend on the specific contaminant being cleaned up. See Section 5 for additional worker health and safety requirements.

Waste Disposal

Because the used absorbent material will contain the contaminant, it may require handling as a hazardous waste. Consult 40 CFR Part 261 and appropriate EPA guidance for definitions and listings of hazardous waste. If the used absorbent material is considered hazardous, it must be treated or disposed of in a RCRA-permitted facility.

Costs

Structural Damage and Repair Costs--

If the surface material is metal or wood and an absorbent is applied quickly, building repair costs should be minimal. Secondary decontamination, if required, may lead to more extensive structural damage and more costly repairs.

Treatment and Disposal Costs--

Treatment costs should be relatively low; absorbent materials and application equipment should not be very expensive. Disposal costs may be appreciable if the wastes are considered hazardous. See Appendix C for an analysis of costs associated with the use of this method.

Future Work

Efforts should be made to increase the applicability of this method to wood and other porous surfaces, and to develop methods for recycling absorbents in large cleanup efforts.

Section 4/Demolition (Method 3)

Information Sources

The bulk of the information in this subsection came from Reference 19.

DEMOLITION (METHOD 3)

General Description

Demolition refers to the total destruction of a building, structure, or piece of equipment. Specific demolition techniques include complete burndown, controlled blasting, wrecking with balls or backhoe-mounted rams, rock splitting, sawing, drilling, and crushing. Many of these techniques have been used in the cleanup of nuclear facilities and military arsenals.

Advantages

Decontamination of the site is achieved by removing all contaminated building materials, structures, and equipment.

Disadvantages

Buildings, structures, and equipment are completely destroyed. Large quantities of contaminated debris must be disposed of. Airborne contamination may occur through fugitive emissions, and workers or nearby residents may be exposed.

State of the Art

Demolition technology is well developed. Many types of demolition techniques have been successfully used in the demolition of nuclear facilities. Demolition also was used in a section of the Frankford Arsenal site (Appendix H). Demolition is used extensively by the construction industry.

Variations of Idea

Demolition may be limited to only those parts of a building or structure that cannot be decontaminated by any other means.

Applicability

Demolition is potentially applicable to all contaminants; however, if the building is highly contaminated with combustibles, explosions may occur during demolition. All materials used to construct buildings, structures, and equipment may be demolished.

Effectiveness

Complete removal of contaminated structural materials from the site is expected.

Engineering Considerations

Building Preparation--

Considerable building preparation activities are required. First, all surfaces must be washed down to minimize dust. Some contaminant residues (e.g., explosives, asbestos, or other toxic contaminants) may have to be neutralized, stabilized, or removed prior to demolition activities to prevent explosions or emissions. Also, some structures within the building may have to be dismantled and removed prior to demolition activities (see Method 4).

Process Description--

Figure 2 is a flow diagram of the demolition process.

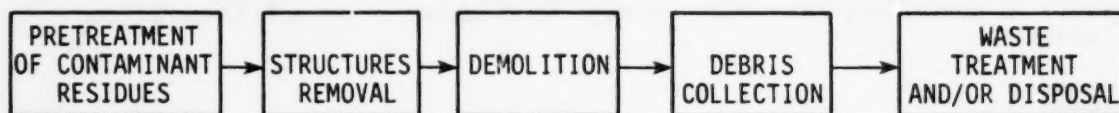


Figure 2. Demolition process flow diagram.

After the building preparation steps have been completed, controlled blasting, wrecking balls, hydraulic rams, controlled burndown, or other methods are used to demolish the building. The debris is then collected or contained for treatment (possibly incineration) and disposal.

Equipment and Support Facilities Needed--

Demolition requires the use of explosives or other demolition equipment, cleanup equipment, water hoses, and personal protective gear.

Time Requirements--

Personnel time could be extensive if considerable building preparation is required. Equipment setup and teardown depend on the demolition technique, but they should require little time. Cleanup time may constitute the largest portion of the total time required. Complete burndown of a 3.6-ha parcel containing 32 small one-story buildings at the Frankford Arsenal site took approximately 12 h.

Safety Requirements

Dynamite or other explosives and heavy machinery constitute process hazards. Accidental detonation of the building is possible if it is heavily

Section 4/Demolition (Method 3)

contaminated with combustible, explosive, or reactive residues. Residues should be pretreated before demolition to eliminate fire and explosion hazards and atmospheric release of toxins.

Personnel hazards may result from high noise and dust levels, and from explosions. Proper eye, ear, head, and clothing protection should be worn. See Section 5 for additional worker health and safety requirements.

Waste Disposal

The debris resulting from demolition will be contaminated and may require handling as a hazardous waste. In some cases, it may be cost-effective to decontaminate the debris before landfilling. Rotary kiln incineration should be evaluated as a treatment method on a case-by-case basis depending on the availability of a permitted incinerator and the Btu value of the waste. Other decontamination techniques described in this manual may also be used to reduce the volume of contaminated waste. Consult 40 CFR Part 261 and other appropriate EPA guidance for definitions and listings of hazardous waste. If the waste is considered hazardous, it must be disposed of in a RCRA-permitted landfill.

Costs

Structural Damage and Repair Costs--

Buildings and structures are completely destroyed. Costs for construction of replacement structures may be incurred.

Treatment and Disposal Costs--

Costs for utilities and fuel for operating the demolition and cleanup equipment should be moderate to high. Costs associated with treating and disposing of the debris may be appreciable. Incineration costs will increase with the noncombustible content of the debris (brick, cement, etc.). See Appendix C for an analysis of costs associated with the use of this method.

Future Work

Methods for desensitizing combustible contaminants prior to demolition need to be developed.

Information Sources

The bulk of the information in this subsection came from References 20 and 21. Use of this method is illustrated in the case studies presented in Appendices D and H.

DISMANTLING (METHOD 4)

General Description

Dismantling refers to the physical removal of selected structures (such as contaminated pipes, tanks, and other process equipment) from buildings or other areas. Dismantling can be the sole activity of decontamination efforts (e.g., removal of contaminated structures from an otherwise clean building), or it can be used in the initial stage of a more complex building decontamination effort (e.g., removal of structures prior to flaming, demolition, or other cleanup techniques).

Advantages

Dismantling is less costly than complete demolition because only those structures that are contaminated are removed.

Disadvantages

Large quantities of contaminated debris must be disposed of.

State of the Art

Dismantling has been used in many decontamination procedures (chiefly in conjunction with asbestos removal and replacement), in the decommissioning of nuclear facilities, and in the cleanup of military arsenals.

Variations of Idea

If no direct contamination hazards are present or if local protection is used effectively, dismantling may be done manually. Remote removal may be necessary if highly contaminated areas prevent direct worker access. Whole structures may be removed at one time (furniture, drains, light fixtures), or segmenting may be necessary prior to removal (piping, tanks, interior vessels of nuclear facilities).

Applicability

Dismantling is potentially applicable to all types of contaminants and to building materials that can be segmented/disassembled.

Effectiveness

In the case of the removal of contaminated structures from an otherwise clean building, complete physical decontamination is possible. When dismantling precedes other decontamination efforts, only partial cleanup can be expected.

Section 4/Dismantling (Method 4)

Engineering Considerations

Process Description--

First, the components to be dismantled are identified, and then a controlled work area is established, isolated, and sealed. Any contaminated loose debris (such as wood or metal scraps) should be removed after a light water spray has been applied to minimize airborne particulates. Penetrating oil is then applied to joints, screws, and nuts that will be removed. A second coat of oil, just prior to their removal, may be necessary. Major structures to be dismantled are then removed by physical labor and/or dismantling equipment. Care should be taken in the use of saws or other friction-producing tools if combustible contaminants are present. Segmenting of large metallic components may be necessary; this can be accomplished through a number of processes, including plasma arc cutting, oxygen burning, explosive cutting, hacksaw and guillotine sawing, and circular and abrasive cutting. Once dismantling is complete, all removed materials are decontaminated or placed in suitable containers and marked for shipment to a suitable disposal site.

Equipment and Support Facilities Needed--

Dismantling requires the following: major tools (saws, blades, etc.) for segmenting and complex removals, depending on the process selected; nonsparking tools, including wrecking bars; water and water sprayer; safety equipment (glasses, coveralls, gloves, hardhats, dust masks, hearing protection, and respirators); air compressor; and miscellaneous items such as storage containers, spare saw blades, penetrating oil, plastic sheeting, fire extinguisher, and heavy duty plastic bags for disposal of the waste. Most equipment needed for dismantling procedures is readily available from commercial manufacturers.

Time Requirements--

The decontamination time requirements will vary depending on the type and quantity of the structures to be dismantled and the magnitude of removal operations (simple physical removal of furniture, for example, versus segmenting or removal of fixed internal structures such as floor drains or ventilation systems).

Safety Requirements

Basic safety requirements should include the use of all safety equipment described in the equipment section. Depending upon the nature of the contaminant, additional safety precautions may be necessary. Sparkproof tools are of particular importance when working on equipment or structures contaminated by combustibles. Toxic fumes are possible from metal welding, cutting, or burning operations. Safety glasses should offer protection from ultraviolet radiation generated by welding arcs. See Section 5 for additional worker health and safety requirements.

Waste Disposal

Dismantled and removed structures will still be contaminated with residues and cannot be reused or sold for scrap without further treatment. Depending on the recycle value of the dismantled materials, additional decontamination steps (such as acid etching or solvent washing) may be warranted. If not, the contaminated material may require disposal as a hazardous waste. Consult 40 CFR Part 261 and appropriate EPA guidance for definitions and listings of hazardous waste. If the wastes are considered hazardous, they must be disposed of in a RCRA-permitted facility.

Costs

Structural Damage and Repair Costs--

Unless decontaminated, dismantled parts cannot be reused. Replacement costs may be incurred.

Treatment and Disposal Costs--

Treatment costs should be moderate to high, depending on the quantity and magnitude of operation. Costs for utilities and fuel should be low. Equipment, materials, and personnel comprise the bulk of the treatment costs, and their magnitude will depend on the size and type of the dismantling operation. Costs will be incurred for decontamination or disposal of the dismantled structure. See Appendix C for an analysis of costs associated with the use of this method.

Future Work

Research could be devoted to developing less expensive dismantling equipment for use in major segmenting operations.

Information Sources

The bulk of the information in this subsection came from References 20 and 21. Use of this method is illustrated in the case studies presented in Appendices D, E, G, H, J, and K.

DUSTING/VACUUMING/WIPING (METHOD 5)

General Description

This method is simply the physical removal of hazardous dust and particles from building and equipment surfaces by common cleaning techniques.

Section 4/Dusting-Vacuuming-Wiping (Method 5)

Advantages

Small volumes of waste or wastewater are generated. Wastes are contained in vacuum cleaner bags or on wipe cloths and easily disposed of.

Disadvantages

Fugitive dusts created by the dusting or vacuuming action may spread contamination. Also, if the source of the contaminated particulates is from outside a building, vacuuming/dusting efforts inside may be ineffective until the external source is controlled. See the Sontag Road area case study (Appendix F) for an example.

State of the Art

Dusting/vacuuming/wiping is the state-of-the-art method for removing dioxin-contaminated dust from the interior of homes and buildings (see Appendices D and F).

Variations of Idea

Variations include vacuuming with a commercial or industrial-type vacuum; dusting off surfaces such as ledges, sills, pipes, etc., with a moist cloth or wipe; and brushing or sweeping up hazardous debris.

Applicability

Dusting and vacuuming are applicable to all types of particulate contaminants, including dioxin, lead, PCB's, pesticides, and asbestos fibers. The methods are applicable to all types of surfaces.

Effectiveness

Residue levels should be low after thorough vacuuming or dusting. If residue levels are unacceptable after vacuuming or dusting, wiping with a water- or solvent-soaked cloth may be necessary.

Engineering Considerations

Process Description--

Vacuuming is performed using a commercial or industrial vacuum equipped with a high-efficiency particulate air (HEPA) filter. The vacuum cleaner bag containing the contaminated particulates is disposed of as a hazardous waste.

Dusting/wiping uses a damp cloth or wipe (soaked with water or solvent) to remove dust from surfaces not practically treatable with a vacuum. The cloth or wipe is also disposed of as a hazardous waste.

Brushing or sweeping is used to clean up coarse debris.

Section 4/Dusting-Vacuuming-Wiping (Method 5)

Equipment and Support Facilities Needed--

Needed equipment includes a HEPA-filter-equipped vacuum (commercial or industrial), cloths or wipes, water, solvent, containers for packaging contaminated waste or debris, and Level C protective gear.

Time Requirements--

Minimal time will be required for setup of the equipment. Labor requirements for the process should be moderate, depending on the size and complexity of the surface area to be cleaned. Minimal time will be required for packaging debris and dismantling and removing equipment.

Safety Requirements

Toxic dust could be hazardous to personnel. Protective clothing and appropriate respirators should be required for workers. See Section 5 for additional worker health and safety requirements.

Waste Disposal

The collected dust and debris may be considered a hazardous waste. Consult 40 CFR Part 261 and appropriate EPA guidance for definitions and listings of hazardous waste. If the waste is considered hazardous, it must be disposed of in a RCRA-permitted facility.

Costs

Structural Damage and Repair Costs--

These costs should be negligible or zero.

Treatment and Disposal Costs--

The costs associated with this type of treatment are relatively low. Disposal costs should also be low. See Appendix C for an analysis of costs associated with the use of this method.

Future Work

The efficiency of this method needs to be documented.

Information Sources

The bulk of the information in this subsection came from References 20 and 22. Use of this method is illustrated in the case studies presented in Appendices D, E, F, G, and H.

ENCAPSULATION/ENCLOSURE (METHOD 6)

General Description

Contaminants or contaminated structures are physically separated from building occupants and the ambient environment by a barrier. An encapsulating or enclosing physical barrier may take different forms; among them are plaster, epoxy resins, and concrete casts and walls. Acting as an impenetrable shield, a barrier keeps contaminants inside and away from clean areas, thereby alleviating the hazard. As a result, contamination of part of a structure will not result in the contamination of adjacent areas.

Painting and coating techniques may also be classified under encapsulation. These techniques are discussed separately in Methods 9 and 19. Encapsulation and enclosure of asbestos-containing materials are discussed in Methods 1B and 1C.

Advantages

Large volumes of contaminated debris are not created.

Disadvantages

Encapsulated structures are usually rendered inaccessible or inoperable since they are physically sealed off by the barrier or enclosure.

State of the Art

Encapsulation has been used on damaged asbestos insulation, leaky PCB-contaminated electrical transformers, and open maintenance pits and sumps contaminated by heavy metals.

Variations of Idea

See also Methods 1B, 1C, 9, and 19.

Applicability

Encapsulation is applicable to all contaminants if there is a means of constructing a physical barrier. It can be used on all building materials.

Effectiveness

Complete establishment of an impenetrable barrier is anticipated. This would allow for complete (100 percent) isolation of contaminated structures.

Engineering Considerations

Process Description--

Any loose contaminants (liquids, sludges) are first removed and/or cleaned so the contaminated structure is easily accessible. The impenetrable barrier is then constructed. At the Frankford Arsenal, for example, where asbestos and PCB encapsulation procedures were used, loose frayed insulation and spill material were first cleaned up; then the insulation was encapsulated with a plaster cast (medical type), and the PCB-contaminated transformers were coated with epoxy resins. Sludge was removed from contaminated sumps and pits, and the structures were filled with concrete and/or sand to render them inoperable (see Appendix H).

Equipment and Support Facilities Needed--

Encapsulation requires shearing equipment (scissors, etc.) to remove loose solid materials, pumping equipment to remove liquid contaminants, barrier materials (e.g., plaster cast, water, epoxy, sand, concrete), application equipment, and personal protective gear. Most equipment needed for encapsulation procedures is readily available from commercial manufacturers.

Time Requirements--

Moderate time is needed for the removal of loose solid or liquid contaminated wastes, application of encapsulating materials, and a period for the encapsulating material to take final form (hardening of concrete, etc.).

Safety Requirements

Basic safety requirements for all encapsulating procedures should include full-body protective coveralls and foot cover. Additional equipment needed will depend on the specific contaminant that is being encapsulated. For example, when encapsulating asbestos, workers should wear appropriate respirators. See Section 5 for additional worker health and safety requirements.

Waste Disposal

Depending on the situation, contaminated liquid or solid debris may have to be removed and disposed of before encapsulation takes place. Because the hazard is alleviated through isolation of the contaminants, no structural materials must be removed.

Costs

Structural Damage and Repair Costs--

In most cases, encapsulated sections of structures will be unable to perform their original functions. As a result, costs may be incurred for replacement structures.

Section 4/Gritblasting (Method 7)

Treatment and Disposal Costs--

Overall costs should be moderate; costs for utilities and fuel should be low. Equipment and materials costs will make up most of the treatment costs. Personnel costs should not be very large. Disposal costs should be low.

Future Work

This technique is generally well developed. Research should concentrate on developing encapsulating materials and techniques that are relatively inexpensive and contaminant-specific.

Information Sources

The bulk of the information in this subsection came from References 20, 21, 23, and 24.

GRITBLASTING (METHOD 7)

General Description

Gritblasting is a surface removal technique in which an abrasive material is used for uniform removal of contaminated surface layers from a building or structure.

Advantages

Gritblasting is a widely used surface-removal technique. It can simultaneously and readily remove paint and contaminants near the surface.

Disadvantages

Large amounts of dust and debris are generated. This method is effective only as a surface treatment. Gritblasting can potentially detonate pockets of combustible contaminants. A large quantity of abrasive is required, and this method is relatively slow.

State of the Art

This technology is well developed. Gritblasting has been used since 1870 to remove surface layers from metallic and ceramic surfaces, and is currently used extensively throughout industry. For example, sandblasting is commonly used to clean the surfaces of old brick and stone buildings. A large number of gritblasting equipment manufacturers and contractors are available.

Variations of Idea

Steel pellets, sand, alumina, or glass beads may be used as the abrasive. Remote-control gritblasters are available.

Applicability

The gritblasting method is potentially applicable to all surface contaminants except highly toxic residues (e.g., asbestos, dioxins) and some highly sensitive explosives (e.g., lead azide, lead styphnate). This method is applicable to all surface materials except glass, transite, and Plexiglas.

Effectiveness

Surface layer contaminants are completely removed by gritblasting; however, this method is ineffective for depths greater than about 0.5 to 1.5 cm. Corners may not be gritblasted as effectively as flat surfaces. Because abrasive is "sprayed," the method is applicable to many hard-to-reach areas (ceilings, behind equipment, etc.).

Engineering Considerations

Building Preparation--

Obstructions, such as pipes bolted to a wall, may require removal prior to treatment.

Process Description--

Figure 3 presents a flow diagram of gritblasting operations.

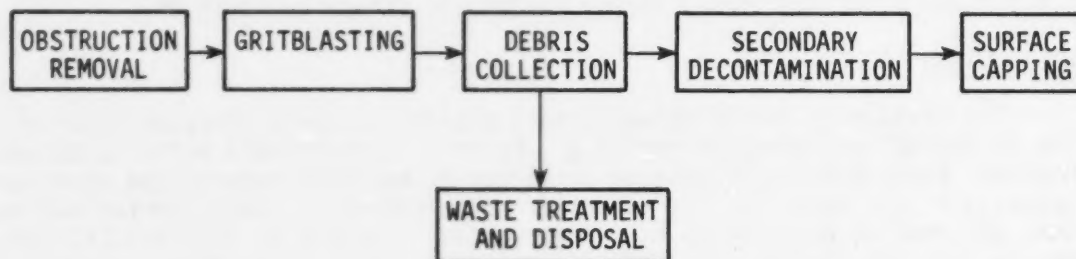


Figure 3. Gritblasting process flow diagram.

Once all obstructions have been removed, an abrasive (steel pellets, sand, alumina, or glass beads) is spray-applied to the building surface. The removed surface material and abrasive are collected and placed in appropriate containers for treatment and/or disposal. The building is then cleaned of residual dust by vacuuming and/or waterwashing. If necessary, secondary

Section 4/Gritblasting (Method 7)

decontamination is performed to remove contaminants that have penetrated building materials beyond the surface layer.

Equipment and Support Facilities Needed--

Gritblasting equipment requirements include a blast-gun, pressure lines, abrasive, and an air compressor. These components are illustrated in Figure 4. In addition, a debris/dust collection system, cleanup equipment, and personal protective gear are required.

Time Requirements--

Minimal setup time is required, depending on whether obstructions must be removed.

Personnel time is needed for gritblasting, collection of debris, transport of debris to a waste management facility, and cleanup--all labor-intensive tasks. Remote control units may decrease labor time, but at the expense of capital cost. Approximately 35 m² can be gritblasted per 8-h day.

Equipment removal (mainly of blasting equipment) requires minimal tear-down time. Cleanup requires the vacuuming or waterspraying of walls and the collection of all removed material and spent abrasive for transport to a waste disposal site.

Safety Requirements

Potential personnel hazards consist of dust inhalation and dust explosion (if combustible material is gritblasted). To minimize these hazards, the area should be washed down and wet processes should be used. Personal protective equipment should include face hoods, respirators, and protective clothing. See Section 5 for additional worker health and safety requirements.

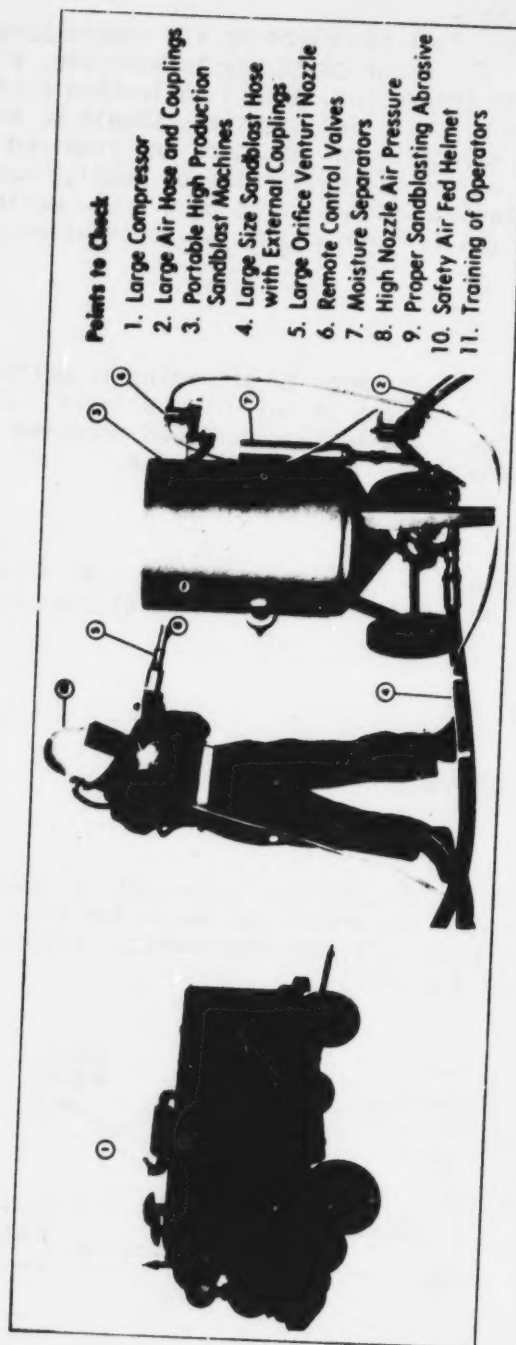
Waste Disposal

The mixture of contaminated surface debris and spent abrasive material can be thermally decontaminated (e.g., by kiln incineration) before disposal. However, large amounts of residue still can be expected because the abrasives normally do not burn. If the wastes are not treated to remove contamination, they may require disposal as hazardous wastes. Consult 40 CFR Part 261 and appropriate EPA guidance for definitions and listings of hazardous waste. If the wastes are considered hazardous, they must be disposed of in a RCRA-permitted facility.

Costs

Structural Damage and Repair Costs--

In most cases, minimal structural damage will result because only the surface layer is removed. Costs for capping the treated surface may be incurred.



Points to Check

1. Large Compressor
2. Large Air Hose and Couplings
3. Portable High Production Sandblast Machines
4. Large Size Sandblast Hose with External Couplings
5. Large Orifice Venturi Nozzle
6. Remote Control Valves
7. Moisture Separators
8. High Nozzle Air Pressure
9. Proper Sandblasting Abrasive
10. Safety Air Fed Helmet
11. Training of Operators

Figure 4. Equipment components of a gritblasting system.

Manufacturer's brochure.

Section 4/Hydroblasting-Waterwashing (Method 8)

Treatment and Disposal Costs--

Costs for utilities and fuel for electric air compressors and vacuum systems will be incurred. Equipment costs may be moderate, as this method requires a gritblaster, air compressor, debris collection system, and dust-suppression system. Material costs for abrasives should be moderate. This method is labor-intensive and costly as manhours are required for manual operation of gritblasting equipment, collection of debris, waste disposal, and cleanup. If the waste material is considered hazardous, waste disposal costs will be high. See Appendix C for an analysis of costs associated with the use of this method.

Future Work

Experimental effort should be made to determine if gritblasting will detonate residual combustible wastes on building surfaces. Engineering development is needed for methods of collecting dust and treating waste materials generated during the process to recover the abrasive.

Information Sources

The bulk of the information in this subsection came from Reference 20. Use of this method is illustrated in the case studies presented in Appendices G, H, and K.

HYDROBLASTING/WATERWASHING (METHOD 8)

General Description

A high-pressure (3500 to 350,000 kPa) water jet is used to remove contaminated debris from surfaces. The debris and water are then collected and thermally, physically, or chemically decontaminated. Figure 5 is a schematic diagram of the hydroblasting process.

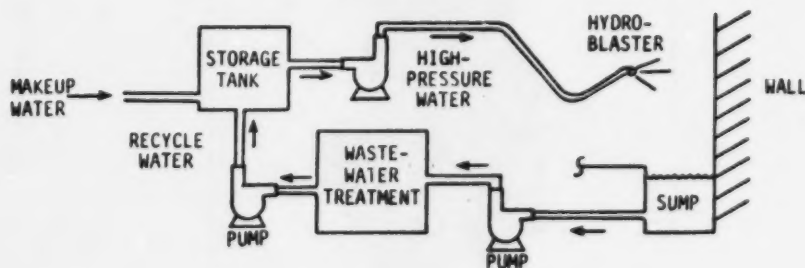


Figure 5. Schematic diagram of the hydroblasting process.

Advantages

Hydroblasting offers a relatively inexpensive, nonhazardous surface decontamination technique that uses off-the-shelf equipment. Hydroblasting can very easily incorporate variations such as hot or cold water, abrasives, solvents, surfactants, and varied pressures. Many manufacturers produce a wide range of hydroblasting systems and high-pressure pumps.

Disadvantages

Hydroblasting may not effectively remove contaminants that have penetrated the surface layer. Also, large amounts of contaminated liquids will have to be collected and treated.

State of the Art

Hydroblasting has been used to remove explosives from projectiles, to decontaminate military vehicles, and to decontaminate nuclear facilities. Hydroblasting also has been employed commercially to clean bridges, buildings, heavy machinery, highways, ships, metal coatings, railroad cars, heat exchanger tubes, reactors, piping, etc. Off-the-shelf equipment is available from many manufacturers and distributors.

Variations of Idea

Remotely operated hydroblasting rigs can be designed and used on walls or floors. Surfactants, caustic solutions, or commercial cleaners can be added to the water to decrease surface tension and increase effectiveness, and possibly increase the depth of penetration. Solvents such as acetone can be used in combination with water or can replace water altogether to solubilize contaminants. Sand or other abrasives can be used to increase surface removal effectiveness (add-on attachments are available from the manufacturers).

Applicability

At present, hydroblasting is applicable to explosives, heavy metals, and radioactive contaminants. The potential exists for applicability to other contaminants. This method can be used on contaminated concrete, brick, metal, and other materials. It is not applicable to wooden or fiberboard materials.

Effectiveness

Complete removal of surface contamination is anticipated. On the average, hydroblasting removes 0.5 to 1.0 cm of concrete surface at the rate of 35 m²/h. High pressures and chemical additives can remove contaminants from below the surface.

Other methods may be needed to remove or decontaminate any residual contaminants that have penetrated beyond the surface layer of material.

Engineering Considerations

Building Preparation--

Before decontamination activities begin, existing sumps or water collection systems are checked for leaks. Installation of sumps and external water storage tanks may be necessary.

Process Description--

A flow diagram of the hydroblasting process is presented in Figure 6. High pressure water (3500 to 350,000 kPa) is applied to building or equipment surfaces. The removed surface debris and spent water are collected in a sump and treated to separate the solids. The water is recycled to storage tanks where makeup water is added. Secondary decontamination techniques may be required to remove subsurface contamination.

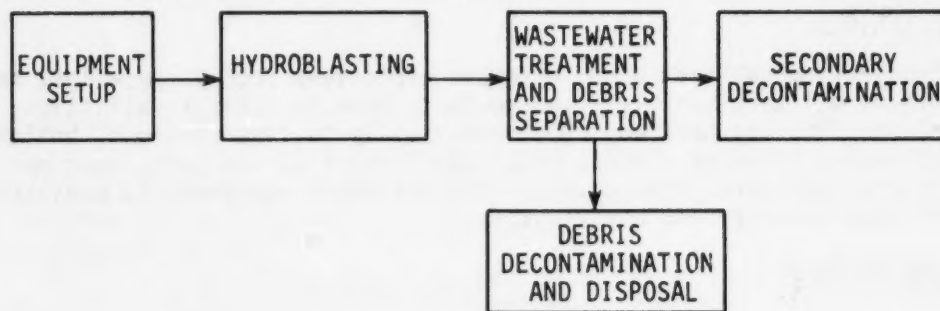


Figure 6. Hydroblasting process flow diagram.

Equipment and Support Facilities Needed--

Hydroblasting requires a water-blasting system consisting of high-pressure pump hoses and nozzles, water collection sumps, water storage tanks, and conventional water pumps. In addition, protective clothing is required for workers.

Time Requirements--

Minimal time is required to inspect an existing sump system or to install a new one (if necessary), and to set up the hydroblast system.

Personnel time could be extensive because all surfaces must be treated. Automated hydroblasting systems will decrease personnel time, but will increase equipment costs. Decontamination time could be moderate to long depending upon the technique chosen for the decontamination of debris and the secondary treatments.

Equipment removal and cleanup times should be low to moderate. The collection system will need to be rinsed of debris and all contamination, and the spent water must be treated.

Safety Requirements

No process hazards are anticipated. High-pressure water lines are a potential hazard for workers. Glasses, gloves, and protective clothing should be worn by all personnel to avoid contact with the contaminant. If sand, solvents, or caustic solutions are added to the water, personal protection should be increased accordingly. Hearing protection may also be required. See Section 5 for additional worker health and safety requirements.

Waste Disposal

The removed surface debris and spent water are collected in a sump system. Solids are separated by settling, and the liquid portion is recycled. Solids and spent liquids may be considered hazardous wastes. Consult 40 CFR Part 261 and appropriate EPA guidance for definitions and listings of hazardous wastes. If the solids or liquids are considered hazardous, they must be disposed of in a RCRA-permitted landfill. Alternatively, the solids may be treated in a RCRA-permitted incinerator and the liquid pretreated to remove contaminants prior to discharge to an NPDES-permitted wastewater treatment facility. Activated charcoal alone or in combination with sand may be used as the filter media, but it will also require treatment or disposal as a hazardous waste.

Costs

Structural Damage and Repair Costs--

Water may damage insulation and wooden surfaces. The treated surface of some materials may require painting or other refinishing methods. Repair costs should be low to moderate.

Treatment and Disposal Costs--

A hydroblaster can be powered by gas, electricity, or diesel fuel, thus costs for utilities and fuel should be moderate. Equipment costs should be moderate to high. Other material costs to be incurred include those for water and solvents, surfactants, and abrasives (if added). Personnel costs could be high. Automated systems can decrease personnel costs but will increase equipment costs. Disposal costs will be moderate to high, depending on the volume of waste generated and whether or not it is considered hazardous. See Appendix C for an analysis of costs associated with the use of this method.

Future Work

More information and experimental testing are needed for selecting a treatment technique to remove small quantities of contaminants from large quantities of water. Decontamination and disposal techniques are also needed for the surface debris.

Section 4/Painting-Coating (Method 9)

Information Sources

The bulk of the information in this subsection came from References 20, 21, and 25. Use of this method is illustrated in the case studies presented in Appendices G, H, and J.

PAINTING/COATING (METHOD 9)

Four specific decontamination techniques fall under the general heading of painting/coating: 1) the removal of old layers of paint containing high levels of toxic metals such as lead, 2) the use of fixative/stabilizer paint coatings, 3) the use of adhesive-backed strippable coatings, and 4) the use of the K-20 sealant.

The K-20 sealant method of decontamination is still in the developmental stages and so is described separately in Method 19. The other three techniques are discussed here.

LEAD-BASED PAINT REMOVAL (METHOD 9A)

General Description

In previous years, paints containing high levels of lead were often used on the walls of interior building surfaces. Such paints are still used industrially to coat piping and other metal structures. With age, these paints can crack and peel, presenting a potential health hazard to building occupants. Restoration of Superfund buildings in which lead-based paints were previously used may require their removal.

Paint containing lead in excess of 0.06 percent is removed from building surfaces by commercially available paint removers and/or physical means (scraping, scrubbing, waterwashing). The removed paint waste is placed in sealed containers and disposed of appropriately. Surfaces are then repainted with new paint having a lead content of no more than 0.06 percent by weight.

Repainting does not always take place immediately after removal of the old paint. Action following paint removal depends on the projected future use of the area and the degree of contamination. Resurfacing or further decontamination efforts may be necessary.

Advantages

This method is simple, and large investments in equipment are not required.

Disadvantages

Stripping/painting are labor-intensive operations and cannot be automated.

State of the Art

Paint removal and replacement have been used as cleanup techniques in many buildings (commercial, industrial, residential) containing high-lead-based and other heavy-metal-based paints, and in buildings contaminated with radioactive residues.

Variations of Idea

Other toxic metals such as cadmium, chromium, or mercury were also used in interior paints. Similar concern for toxic effects on occupants should be considered if such compounds are found inside Superfund buildings that are being restored for future use. Buildings found to contain radiation contamination may also require paint removal to eliminate all contamination.

Applicability

This method can be used on all painted surfaces; it is most useful when contaminants are on the surface or between layers of paint.

Effectiveness

Decontamination efforts have indicated that paint removal can result in reduced ambient air concentrations of lead, cadmium, chromium, mercury, and radioactive contaminants.

Engineering Considerations

Process Description--

A controlled area is initially established that surrounds the areas to be decontaminated, and plastic sheeting is placed beneath the working area. Peeling paint is then removed from surfaces through a combination of commercial paint removers (such as methylene chloride preparations), hand scraping, waterwashing, and detergent scrubbing. This combination of removal methods should allow all surface areas of a building to be reached and affected.

Paint wastes accumulate on the plastic ground covering. When paint removal is complete, the plastic is rolled up, securely sealed, labeled,

Section 4/Lead-Based Paint Removal (Method 9A)

placed into storage containers, and disposed of appropriately. Building surfaces are then repainted in a conventional manner.

Equipment and Support Facilities Needed--

Paint removal requires hand-scraping tools, wire brushes, paint removers, water-wash hoses, detergent, plastic sheeting material, safety equipment (coveralls, head covers, goggles, disposable breathing masks), low-lead paint, and paint applicators (brushes, rollers). All equipment needed for paint removal and replacement is available from commercial manufacturers.

Time Requirements--

Decontamination time will depend on the total surface area to be treated. Paint removal will usually take longer than the application of new paint.

Safety Requirements

Because of the possibility of exposure to airborne contaminants, a training program should be conducted and safety equipment (described earlier) should be used. Respirators to protect against organic solvents in paint removers may be necessary. Biological monitoring methods are available for lead, cadmium, chromium, and mercury. See Section 5 for additional worker health and safety requirements.

Waste Disposal

Since the wastes generated are known to be contaminated with lead or other heavy metals, they may be considered hazardous under RCRA. Consult 40 CFR Part 261 and appropriate EPA guidance for definitions and listings of hazardous wastes. If the paint wastes are considered hazardous, they must be disposed of in a RCRA-permitted facility.

Costs

Structural Damage and Repair Costs--

Paint removal will not result in large building renovation costs. Major costs incurred will be for repainting or resurfacing.

Treatment and Disposal Costs--

Treatment costs should be moderate and composed primarily of materials and labor. Disposal costs will depend on whether or not the residues must be handled as a hazardous waste. See Appendix C for an analysis of costs associated with the use of this method.

Future Work

This technique is fairly straightforward and well developed. Research into remotely operated paint removal equipment is a possibility.

FIXATIVE/STABILIZER COATINGS (METHOD 9B)

General Description

Various agents can be used as coatings on contaminated residues to fix or stabilize the contaminant in place and decrease or eliminate exposure hazards. Potentially useful stabilizing agents include molten and solid waxes, carbowaxes (polyoxyethylene glycol), organic dyes, epoxy paint films, and polyester resins. The stabilized contaminants can be left in place or removed later by a secondary treatment. In some cases, the stabilizer/fixative coating is applied in situ to desensitize a contaminant (such as an explosive residue) and prevent reaction or ignition during some other phase of the decontamination process (for example, to prevent explosions during dismantling or demolition).

Advantages

The level of contamination to which building occupants are exposed is reduced. No hazardous wastes are generated. Explosion and ignition hazards are avoided.

Disadvantages

Toxic contaminants remain on the site; monitoring of the effectiveness of the barrier coating is required over its lifetime. Removal at a later date may be required.

State of the Art

Stabilizers are widely used to desensitize combustible contaminants from detonation by accidental shock and also have been used to reduce radioactive contaminant levels at nuclear facilities.

Variations of Idea

Waxes can be dissolved in a volatile organic solvent before application or loaded with a reactant that will help dissolve and/or decompose contaminants upon contact. The contaminant-bearing wax can be left in place or physically removed.

Applicability

Documented use has been found only for PCB's, explosives, and radioactive contaminants, although coatings have the potential to be used against other types of hazardous contaminants. See also Method 19.

This technique is applicable to all building materials.

Section 4/Fixative-Stabilizer Coatings (Method 9B)

Effectiveness

No removal of contaminants is achieved; contaminants remain in place in stabilized, immobilized, or desensitized condition. The efficiency, as measured by reductions in ambient air levels, ranges from about 10 percent to a factor of two- to three-fold, depending on the fixative/stabilizer used.

Engineering Considerations

Process Description--

Coatings can be applied in several ways: 1) in molten form as fine particles ($<20\text{ }\mu\text{m}$) in an aqueous solution containing a wetting agent; 2) by drying and simultaneously coating residues; 3) by dissolving in a solvent, with the option of evaporating the solvent; and 4) by first soaking the contaminant with water and then applying a dye solution.

Coatings are usually applied in the manner of conventional painting. After the coating has dried, a secondary treatment may take place (if necessary). In some cases, a solvent wash can be used after a stabilizer coating has been applied to remove the desensitized contaminants.

Equipment and Support Facilities Needed--

An agitation tank for preparation of the mix, and painting equipment for application of the mix are needed.

Time Requirements--

Minimal setup time is required. Personnel time should be equivalent to the time required for Method 9A. Desensitization occurs rapidly; however, the time required to verify adequate desensitization is not known. Minimal tear-down time is required for the removal of application equipment.

Safety Requirements

Hazards due to solvent flammability and toxicity should be considered. Proper personal protective equipment is required during applications and will vary with the type of solvent and contaminant. See Section 5 for additional worker health and safety requirements.

Waste Disposal

Little or no wastes other than used applicators (such as paint brushes or rollers) are generated.

Costs

Structural Damage and Repair Costs--

None are anticipated.

Section 4/Strippable Coatings (Method 9C)

Treatment and Disposal Costs--

Treatment costs include those for utilities and fuel, equipment, materials (the cost of stabilizer compounds may be substantial, depending on the quantity required), and manpower for the coating application. Disposal costs should be minimal.

Future Work

Experimental work to determine the degree of immobilization or desensitization necessary for complete safety is needed. Also, methods need to be established to ensure intimate and lasting contact of the stabilizer with the contaminants of concern.

STRIPPABLE COATINGS (METHOD 9C)

General Description

Compounds that bind with contaminants are mixed with a polymer, applied to a contaminated surface, and subsequently removed to achieve decontamination.

Advantages

The stripped coating physically holds or traps the contaminant for easier handling and disposal.

Disadvantages

The polymer may bind not only to the contaminant, but also to the surface of the wall or item on which it is applied (strippability depends on its properties and those of the surface). In this case, large volumes of wastes may result, and the building or structural surface may be damaged.

State of the Art

Polymer coating technology has been studied extensively and used in decommissioning nuclear facilities.

Variations of Idea

A chemical reactant could be added to the polymer, which would react with the contaminant in situ to detoxify it or eliminate its hazardous properties, thereby circumventing the need for secondary decontamination.

Section 4/Strippable Coatings (Method 9C)

Applicability

The method should be applicable to all contaminants and materials. Different polymer formulations may be required for various building materials.

Effectiveness

Ideally, a strippable coating should remove all the contaminants it contacts, especially on smooth surfaces. There is a potential for the coating not to reach all the contamination on rough surfaces, especially if it has a high surface tension or if the polymer molecules are too large to fit in the surface pores. Secondary treatment may be needed, depending on how effective the polymer is in removing the contaminant, and how deeply the contaminant has penetrated the material. Secondary treatment of metallic surfaces is not expected.

Engineering Considerations

Building Preparation--

Paint removal may be needed prior to application of the coating.

Process Description--

A polymer mixture is applied to the surface and allowed to react (polymerize) and coat the surface. As it polymerizes, the contaminant becomes entrained in the lattice or attached to the polymer molecules. The polymer layer is peeled off and the residue is removed with it. It may be possible, in some cases, to add chemicals to the mixture to inactivate the contaminants.

Cleanup requirements involve the removal of the strippable coating from all surfaces.

Equipment and Support Facilities Needed--

The following equipment and support facilities will be necessary: tanks for storage of either the polymer mixture or components of the mixture; spraying, brushing, or other application equipment; and scraping or peeling equipment. Heating equipment may be needed to initiate the reaction that activates the polymer.

Time Requirements--

Setup and personnel time should be equivalent to that required for Method 9A. Decontamination time will depend on the nature of reactants in the coating and the contaminant diffusion rates. The time required to verify decontamination is not known. Minimal tear-down time will be needed for equipment removal. Cleanup will require removing the strippable coating for disposal.

Safety Requirements

The necessary personnel protection and safety requirements will be determined by the hazards associated with the contaminant as well as with the

polymer. Personnel should avoid contact with the polymer. Protective clothing, gloves, and eye protection are recommended. If the monomer is hazardous (e.g., vinyl chloride, solvent-based, etc.), additional protection such as respirators will be required. See Section 5 for additional worker health and safety requirements.

Waste Disposal

Debris resulting from use of this method may be considered a hazardous waste. Consult 40 CFR Part 261 and appropriate EPA guidance for definitions and listings of hazardous wastes. If the waste is considered hazardous, it must be treated in a RCRA-permitted incinerator or disposed of in a RCRA-permitted landfill.

Costs

Structural Damage and Repair Costs--

No damage to the building is expected.

Treatment and Disposal Costs--

Costs for utilities and fuel should be minimal. Equipment is available at low cost. Manpower costs should be similar to those required for painting. If the waste is hazardous under RCRA, the costs for disposal will be relatively high.

Future Work

Polymer coating formulations, application and removal techniques, and maximization of removal efficiencies need development through experimental work.

Information Sources

The bulk of the information in this subsection came from References 20 and 22. Use of this method is illustrated in the case studies presented in Appendices D, G, H, and J.

SCARIFICATION (METHOD 10)

General Description

This technique is capable of removing up to 2.5 cm of surface layer from concrete or similar materials. The scarifier tool (Scabbler*) consists of

* Macdonald Air Tool Corp., Hackensack, New Jersey.

Section 4/Scarification (Method 10)

pneumatically operated piston heads that strike the surface, causing concrete to chip off. The piston heads (pictured in Figure 7) consist of multipoint tungsten carbide bits.

Advantages

Scarification can achieve a deeper penetration (removal) than most other surface removal techniques. It is suitable for application to both large open areas and small areas.

Disadvantages

The treated surface retains a rough appearance that requires resurfacing. Substantial amounts of contaminated debris (water and concrete) are generated. Contaminant-laden dust is also generated. An explosion potential exists if pockets of combustible wastes are encountered. This method is restricted to use on concrete or concrete-like materials and can only be used in obstruction-free areas.

State of the Art

The scarification technique has been used in the decommissioning of nuclear facilities and in the cleanup of military arsenals.

Variations of Idea

Wall, floor, and hand-held scarifiers are available (see Figure 7). The units may be modified to include a HEPA-filtered vacuum exhaust system to capture contaminated dust.

Applicability

Scarification is potentially applicable to all contaminants except highly toxic residues (e.g., asbestos, dioxins) or highly sensitive explosives.

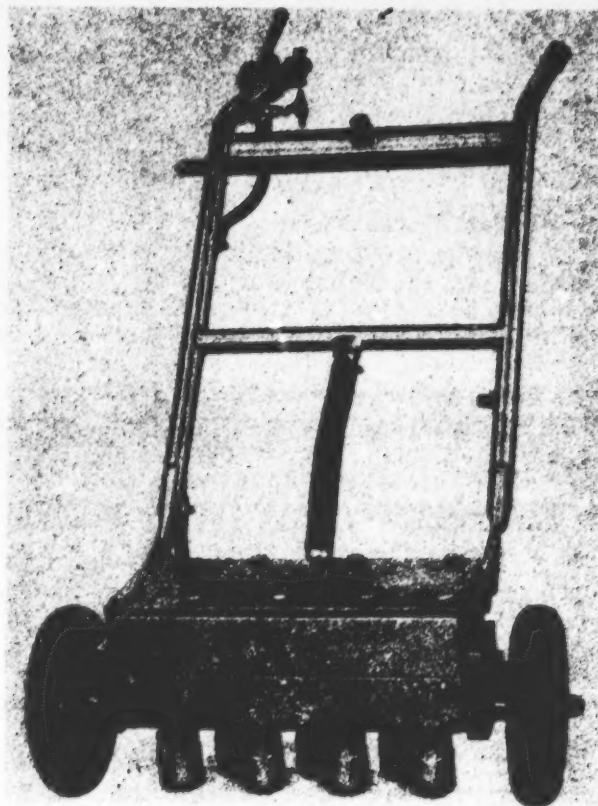
This method is applicable only to concrete (not concrete block) and cement. It is not suitable for hard-to-reach areas such as behind pipes and equipment, unless these obstructions can be removed during building preparation. Applicability is also dependent on interior building configuration. Other treatments must be employed for metal, wood, terracotta, etc.

Effectiveness

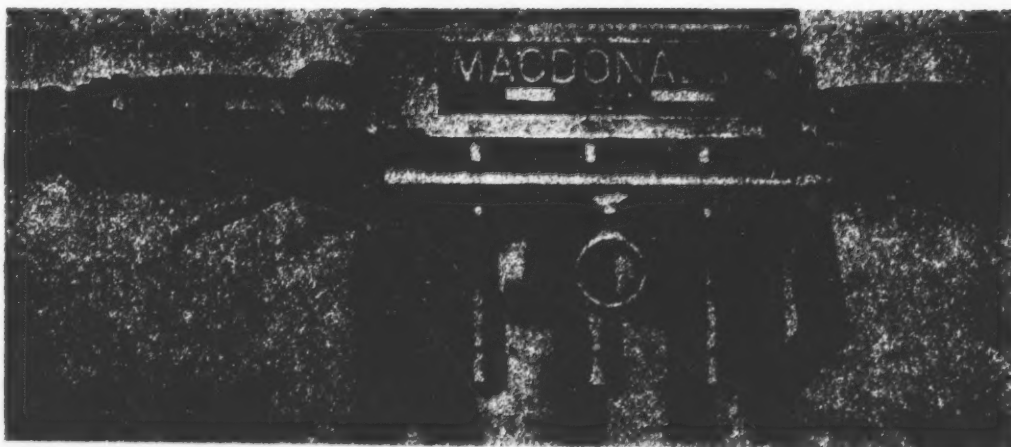
Complete removal of contaminants is possible from the surface layer. Drilling and spalling or other techniques may be required as a secondary decontamination treatment procedure for contaminants that have penetrated the surface deeper than 2.5 cm.



Piston heads



Floor model



Wall model

Figure 7. Scarifier tools.

Source: Reference 21.

Section 4/Scarification (Method 10)

Engineering Considerations

Building Preparation--

Pipes and other equipment are removed where possible to present an obstruction-free area to the scarifier tool.

Process Description--

Figure 8 presents a flow diagram of the scarification method. Obstructions to the scarifier tool are removed during building preparation. The pneumatic scarifier is then used to chip the surface away with its tungsten carbide bits. Water is used to keep dust down.

The removed contaminated debris must be collected with a vacuum or some other system and packaged for either treatment (by incineration or other technique) or disposal. A secondary decontamination treatment can then be used to remove any remaining contaminants that have penetrated deep into the concrete (more than 2.5 cm).

Several variations to the main process are possible. Floor and wall models can be fitted with dust collection systems, hand-held models can be developed for corners or other hard-to-reach areas, and remotely operated scarifier rigs can be used.



Figure 8. Scarification process flow diagram.

Equipment and Support Facilities Needed--

A scarifier unit requires a pressurized air source. A portable generator and air compressors are necessary to furnish the supply of compressed air. A debris collection/packaging system is also needed. The tungsten-carbide bits have an average working life of 80 h under normal conditions.

Time Requirements--

Minimal setup time is required unless obstructions (pipes or other equipment) require removal.

Manhour requirements will be high because removing the surface layer is quite time-consuming, depending on the size of the building and the amount of equipment/obstructions. A remote-control unit may decrease labor time, but

Section 4/Scarification (Method 10)

also may be quite costly unless large open surface areas are present. Decontamination time is probably long because large amounts of material will have to be processed. Actual experiences have shown that a seven-piston floor scarifier can remove approximately 30 m² of surface material per hour and a three-piston wall scarifier can remove 7 to 10 m² of surface material per hour.

Equipment removal requires minimal tear-down time. Cleanup requires considerable time to remove all debris.

Safety Requirements

Personnel hazards may result from high noise levels. Contaminant-laden dust and flying chips could be hazardous. Vibration injury can occur if the vibrating device is hand-held.

Protective clothing, dust respirators, eye protection, and ear protection should be worn. A dust-suppression system such as periodic washdown with water is recommended. See Section 5 for additional worker health and safety requirements.

Waste Disposal

Contaminated debris may be considered hazardous. Consult 40 CFR Part 261 and appropriate EPA guidance for definitions and listings of hazardous wastes. If the waste is considered hazardous, it must be disposed of in a RCRA-permitted facility.

Costs

Structural Damage and Repair Costs--

Scarification leaves a very coarse surface, which may have to be capped with concrete or covered with other materials. Repair costs should be moderate.

Treatment and Disposal Costs--

Costs for utilities and fuel should be low to moderate for the use of electricity for portable power generation. Equipment costs for a scarifier, tungsten-carbide replacement bits, and an air compressor should be moderate to high. Manpower costs will probably be high because the removal rate is quite slow. Disposal costs should be moderate to high, depending on whether or not the wastes are considered hazardous.

Information Sources

The bulk of the information in this subsection came from References 20 and 21. Use of this method is illustrated in the case studies presented in Appendices G and H.

RADKLEEN (METHOD 11)

General Description

Fluorocarbon extraction of contaminants from building materials involves the pressure-spraying of a fluorocarbon solvent onto the contaminated surface followed by collection and purification of the solvent. RadKleen* is an example of a commercial process that uses Freon 113 (1,1,2-trichloro-1,2,2-trifluoroethane or $C_2F_3Cl_3$) as the solvent.

Advantages

Freon 113 is a stable, nonpolar, noncombustible organic solvent suitable for extracting many organic compounds. The compound's low surface tension permits rapid wetting of surfaces, and its low viscosity permits easy particulate separation. Because Freon 113 is a volatile liquid at normal room temperatures, it can be recovered and reclaimed if used in a closed system.

Disadvantages

Secondary treatment is required to treat the used Freon containing the solubilized contaminant. Also, diffusion rates may limit the rate of application.

State of the Art

The RadKleen process is currently used for cleaning radioactive material from various surfaces. It has been applied to chemical agents on small objects, and thus field capability has been demonstrated. Studies have been conducted for agent-contaminated clothing materials, such as polyester-cotton, Nomex, butyl rubber gloves, and charcoal-impregnated cloth. This method has not been demonstrated for removing contaminants from building surfaces, but it looks very promising.

Variations of Idea

Variations include a system that uses an additive to simultaneously extract and decompose the contaminant, and a system that automatically recycles the used solvent through a reactive bed (e.g., activated carbon) for removal of contaminants. Also, the solvent is sometimes heated and applied in the vapor phase to enhance permeability (see Method 14).

Applicability

Because of its solvent properties, Freon 113 may be applicable to many organic contaminants found at Superfund sites. This system has the potential

* Health Physics Systems, Inc., Gainesville, Florida.

for use on many types of building materials: metal, concrete, tile, brick, etc.; painted and unpainted surfaces. Because Freon 113 is electrically nonconductive and compatible with electrical and electronic components, it may be possible to use it to decontaminate operating electronic equipment.

Effectiveness

RadKleen should provide complete removal of Freon 113-soluble contaminants from surfaces. It should be especially effective in the removal of organics and particulates from surfaces, and should penetrate readily into porous materials.

Engineering Considerations

Building Preparation--

The area to be treated is enclosed to facilitate recovery of the solvent and to limit exposures outside the treatment area. Installation of a sump or other collection system for the liquid may also be required.

Process Description--

The solvent (Freon 113) is sprayed under pressure (1400 to 150,000 kPa) for surface cleaning. The solvent removes the contaminating material and is collected, filtered, and distilled for reuse. Washdown or heat may be required to clean and remove all final traces of Freon.

There are several variations of the process. The solvent may be applied to equipment in a vapor phase at atmospheric pressure to enhance permeability. A reactant may be added to the Freon to allow simultaneous extraction/decomposition of the contaminant.

Equipment and Support Facilities Needed--

Fluorocarbon extraction requires a pump, spray system, collection tank, filters, distillation column, enclosure, and electricity.

Time Requirements--

Moderate time may be required to set up and seal the building to prevent release of vapors.

Personnel time is required to apply the spray; however, the method is potentially semiautomatic. Decontamination time for removal of contaminants from surfaces is expected to be quite fast.

Minimal tear-down time is needed to remove the enclosure from the buildings. Equipment removal and cleanup require minimal time.

Safety Requirements

Precaution should be taken when working with high-pressure fluids. Personnel hazards from the inhalation of Freon 113 vapors must be avoided.

Section 4/RadKleen (Method 11)

The NIOSH/OSHA permissible exposure limit in the workplace environment is 1000 ppm Freon 113. Monitoring and respiratory protection may be required for personnel inside the enclosure. See Section 5 for additional worker health and safety requirements.

Freon 113 should not be used in the presence of chemically active metals such as calcium, powdered aluminum, magnesium or beryllium; contact with alloys containing more than 2 percent magnesium results in decomposition.

Waste Disposal

Used solvent will contain contamination and should be treated and recycled wherever possible. Distillation and filtration residues from solvent recycle operations may be considered hazardous wastes. Consult 40 CFR Part 261 and appropriate EPA guidance for definitions and listings of hazardous waste. If the residues are considered hazardous, they must be disposed of in a RCRA-permitted facility.

Costs

Structural Damage and Repair Costs--

There should be little or no structural damage or building repair costs.

Treatment and Disposal Costs--

Costs for utilities and fuel should be minimal. Equipment costs should be moderate to provide for recycling of the solvent. Material costs should be low because the used solvent can be recycled. Personnel costs may be substantial, depending on how much automation is possible. Disposal costs should be moderate to high, depending on whether or not the wastes are considered hazardous.

Future Work

Three areas require further definition. First, studies are needed to establish the effectiveness of removal of contaminants from walls and other building materials. Second, the solubility of contaminants in Freon 113 and other fluorocarbon solvents likely to be found at Superfund sites should be studied. Third, the recycle system needs further engineering development.

Information Sources

The bulk of the information in this subsection came from Reference 20.

SOLVENT WASHING (METHOD 12)

General Description

An organic solvent is circulated across the surface of a building to solubilize contaminants. A schematic diagram of the solvent circulation apparatus is presented in Figure 9. Spent solvent is either thermally or chemically treated to remove contaminants and recycled if no degradation of the solvent occurs during treatment.

Advantages

Removal of contaminated paint is possible if the proper solvent is selected. Depending on the solvent-contaminant match, this can be a very efficient removal system.

Disadvantages

This method is not suitable for intricate structures. Penetration of the solvent into the material matrix, followed by outward diffusion, may require a long time. Residual solvent in building materials may require removal and/or decomposition. The solvent may tend to carry contaminants farther into the wall before outward movement occurs.

State of the Art

The hot solvent soaking process has been shown to be effective in decontamination of PCB-contaminated transformers. This technique has not yet achieved widespread use in building decontamination, although it is beginning to be used in the decommissioning of nuclear facilities. The method needs further development in application, recovery, collection, and efficiency.

Variations of Idea

With a Stanley Steamer configuration, a chemical can be added to the solvent to decontaminate residues. After solvent application, a vacuum may be applied to remove the solvent and the contaminants. A hot solvent soaking process in which contaminated pieces of equipment are filled with a solvent is also possible. Solvent may be applied to buildings in the vapor phase (see Method 14).

Applicability

This method has potential application to a wide range of contaminants, depending on the solvent used. It should also be applicable to most all building materials.

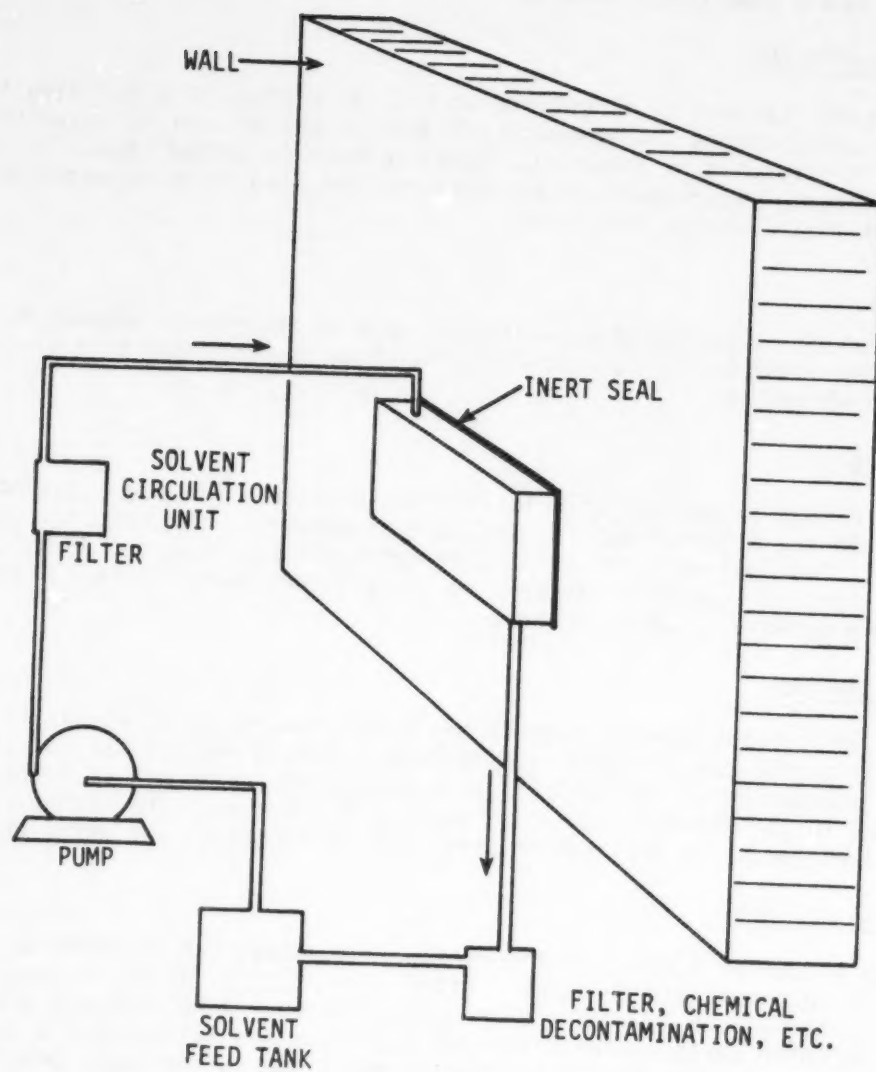


Figure 9. Schematic diagram of the solvent circulation apparatus.

Effectiveness

If the proper solvent is selected, it should extract most, if not all, of the contaminants it contacts on structural surfaces. The primary difficulty is to achieve an inward flux of neat solvent into porous building materials followed by (or concurrent with) an outward flux of solvent contaminated with residues. It is unknown whether this may be accomplished within a realistic period of time; however, the use of a gaseous (i.e., vaporized) solvent may enhance diffusion into and out of building materials.

This technique probably will require more than one application of solvent.

Engineering Considerations

Building Preparation--

All obstructions to the solvent circulation apparatus are removed during building preparation.

Process Description--

Solvent is introduced into a box placed against a wall. The side of the box facing the wall is open with all edges sealed. The solvent is allowed to circulate and penetrate (wet) the surface to dissolve and remove the contaminant. The contaminated solvent is collected at the bottom of the box, passed through a filter or packed carbon bed, and recycled.

It may be extremely difficult to get a tight seal around the solvent circulation apparatus and surface, especially around uneven areas and in hard-to-reach places. This method is only suitable for large open areas of buildings.

Multiple solvent washes and/or some type of secondary treatment may be needed for total removal of the contaminants. Water-wash after decontamination may be necessary to remove the solvent contained in porous materials. Alternatively, heating may be used to volatilize any residual solvent.

Equipment and Support Facilities Needed--

Solvent washing requires a solvent pump, circulation box, collection tank, and recovery system (e.g., filter, neutralizer, distillation column). It may require a condenser if the solvent is vaporized during processing.

Time Requirements--

This method will probably require extensive setup time, depending on obstructions that require removal, the size and configuration of equipment used, and the number of applications required.

Personnel time will probably be low to moderate because of extensive involvement in setup and tear-down, although solvent washing is a passive

Section 4/Solvent Washing (Method 12)

process (only monitors are required during decontamination). Decontamination time is dependent on diffusion and the number of applications required; it could require hours or days.

Equipment removal and tear-down time depends on the size and configuration of equipment.

Safety Requirements

Process hazards consist of explosion or fire hazards from flammable solvents. Personnel hazards depend on the toxicity of the solvent as well as the contaminant. If a volatile flammable solvent is used, explosion-proof equipment and ambient air concentration monitors will be required. Personnel must wear protective clothing and possibly respirators. See Section 5 for additional worker health and safety requirements.

Waste Disposal

The spent solvent and filter residue from the solvent recovery system may be considered hazardous wastes. Consult 40 CFR Part 261 and appropriate EPA guidance for definitions and listings of hazardous wastes. If the wastes are considered hazardous, they must be disposed of in a RCRA-permitted facility.

Costs

Structural Damage and Repair Costs--

No structural damage or repair costs are anticipated.

Treatment and Disposal Costs--

Costs for utilities and fuel should be low. Some electricity and possibly steam will be required. Equipment costs should be moderate to high, depending on the complexity of the solvent recovery system. Moderate to high material costs (solvent) can be expected, depending on the feasibility of recovery. Manpower costs will depend on the operating personnel needed to move the equipment during decontamination as well as for setup and tear-down, which may be extensive. Disposal costs should be moderate to high, depending on whether the wastes are considered hazardous.

Future Work

Specification and design of equipment and process parameters, and solvent selection guidelines are needed.

Information Sources

The bulk of the information in this subsection came from References 20 and 26.

STEAM CLEANING (METHOD 13)

General Description

Steam cleaning physically extracts contaminants from building materials and equipment surfaces. The steam is applied by hand-held wands or automated systems, and the condensate is collected for treatment. Figure 10 shows a vehicle being decontaminated by steam cleaning.

Advantages

Steam cleaning is a relatively inexpensive and simple technique. Depending on the contaminant, thermal decomposition and/or hydrolysis may occur.

Disadvantages

This technique is known to be effective only for surface decontamination. Steam cleaning is a labor-intensive process that is costly if automated. Probably only mechanical removal of contaminants actually takes place because of the limited solubility of many residues in water. Large volumes of contaminated water are generated (although these volumes are less than those generated by the hydroblasting/waterwashing method).

State of the Art

Steam cleaning is the state-of-the-art technique for removing contaminated soil particles from earth moving and drilling equipment. It is also used by explosives handling and manufacturing facilities to remove contaminants from walls, floors, and equipment. Several manufacturers make portable steam cleaning equipment.

Variations of Idea

Variations of the process include generating steam in the form of a water/acetone mixture to enhance contaminant solubility, mixing a wetting agent with the steam, superheating the steam, or using steam-jet systems for high fuel efficiency. Steam can also be externally generated and used to flood an entire building.

Applicability

Currently, steam cleaning is used mainly to remove contaminated particulates and explosive residues; however, an industrial contact indicated that tetryl may detonate in the presence of steam. Laboratory testing has shown steam cleaning to be effective against some chemical warfare agents. These agents are similar in structure to pesticides (especially organophosphates). Steam cleaning is applicable to a wide variety of contaminants and structural materials.



Figure 10. Steam cleaning of a vehicle.

Effectiveness

Removal or reaction of contaminants from the surface should be very good because steam can physically remove the contaminants from the surface. Removal or reaction of contaminants from the subsurface is probably poor as many contaminants have low solubilities in water. Theoretically, steam can be used to remove contaminants from the subsurface if steaming is continued for a long period of time, but this has not been demonstrated. Paint may act as a barrier.

Engineering Considerations

Building Preparation--

Building preparation may require setup of piping ductwork from the sump to exterior holding tanks. Plastic sheeting and other moisture barriers may be needed to protect uncontaminated portions of the structure from water damage. Paint removal may also be required unless a suitable water/solvent system is employed.

If earth-moving and drilling equipment are to be steam cleaned, plastic sheeting should be spread on the ground under the contaminated equipment, and containment barriers should be constructed to allow for collection of the condensate.

Process Description--

Figure 11 presents a flow diagram of the steps involved in the steam cleaning method of decontamination.

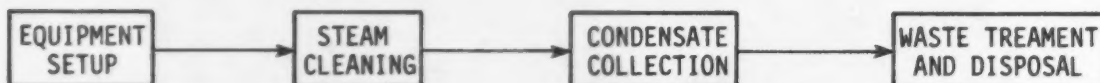


Figure 11. Steam cleaning process flow diagram.

The steam is generated with oil-, gas-, or electric-fired steam generators, and it is applied to building and equipment surfaces by a hand-held wand or an automated system. Figure 12 is a photograph of a steam generator. The condensate, which contains the removed contaminants, is collected and treated to remove and destroy the waste residues.

Equipment and Support Facilities Needed--

Steam cleaning requires steam generators, spray systems, collection sumps, and waste treatment systems. Commercial-scale steam cleaners are available from many manufacturers.



Figure 12. Photograph of a steam generator.

Time Requirements--

Minimal setup time is required, but different collection systems may have to be designed if floor sumps are inadequate. Existing sumps will need to be checked for leaks. A pumping system may be set up to remove condensate continuously.

Personnel time for steam application to equipment is low; personnel time for steam application to buildings may be extensive, depending on the size and complexity of the structure and the effectiveness of the steam in removing the contaminant. Automated steam wands can reduce personnel time for decontamination of large buildings.

Equipment removal requires minimal time. Cleanup may require a water rinse of the building interior or equipment surface. Condensate will need to be rinsed from sumps and collection systems and treated.

Safety Requirements

Potential personnel hazards include steam burns and solvent/steam mixtures that may be toxic. Respiratory protection may be required if a steam/acetone or other steam/solvent mixture is used. Protective clothing (including boots) is recommended in all cases. Additional protection depends on the level and nature of the contaminant. See Section 5 for additional workers health and safety requirements.

Waste Disposal

The contaminated wastewater collected in the sump or containment area must be treated to remove or destroy any waste residues. (An exception to this requirement was made in Times Beach, Missouri, where the contaminated soil will eventually be excavated.) Pretreatment on site or in a municipal wastewater treatment facility will be needed. Treatment residues may be considered hazardous waste. Consult 40 CFR Part 261 and appropriate EPA guidance for definitions and listings of hazardous waste. If the treatment residue is considered hazardous, it must be disposed of in a RCRA-permitted facility.

Costs

Structural Damage and Repair Costs--

These should be minimal.

Treatment and Disposal Costs--

Costs for utilities and fuel should be low because steam is relatively inexpensive to generate. Equipment costs include steam cleaners (which cost \$2000 to \$5000), spray systems, collection sumps, and waste treatment systems. Material costs may include additives, such as surfactants or acetone. Manpower costs may be high because steam must be applied to all surfaces and

Section 4/Vapor-Phase Solvent Extraction (Method 14)

because more than one application may be necessary. Automated steam wands can reduce labor costs, but they increase equipment costs. Waste disposal costs should be moderate to high, depending on whether or not the waste is considered hazardous. See Appendix C for an analysis of costs associated with the use of this method.

Future Work

The degree to which various contaminants can be removed from equipment surfaces and building materials (especially porous materials such as concrete) must be determined. Techniques for treatment of contaminated condensate are needed. Additives and/or co-solvents should be evaluated for their usefulness.

Information Sources

The bulk of the information in this subsection came from References 20 and 21. Use of this method is illustrated in the case study presented in Appendix F.

VAPOR-PHASE SOLVENT EXTRACTION (METHOD 14)

General Description

An organic solvent with a relatively low boiling point (such as acetone) is heated to vaporization and allowed to circulate in a building. The vapors permeate into porous building materials, where they condense, solubilize contaminants, and diffuse outward. The contaminant-laden liquid solvent is collected in a sump and treated to allow recycling of the solvent. Figure 13 is a schematic diagram of the process.

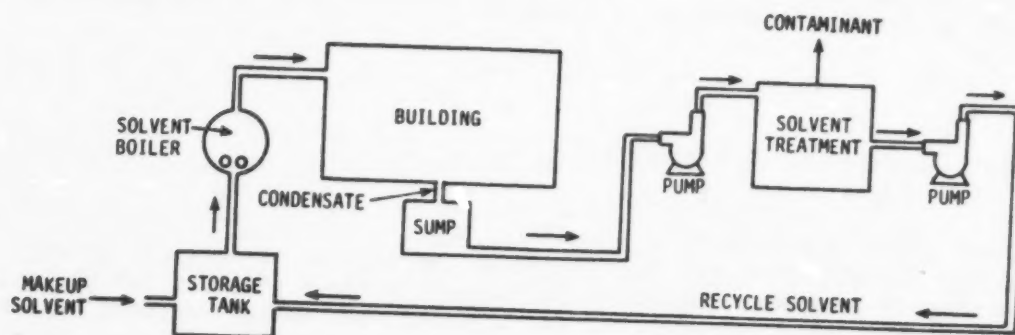


Figure 13. Schematic diagram of the vapor-phase solvent extraction process.

Advantages

This method is well suited to all areas of a building, including intricate structures. Solvent permeability and diffusibility are enhanced by the solvent being in the vapor phase. Removal of contaminated paint is possible if the proper solvent is selected. Depending on the solvent-contaminant match, this may be a very efficient removal system because of the enhanced solubility of contaminants in heated solvent.

Disadvantages

Outward diffusion of solvent laden with contaminants may require long treatment times. The solvent may tend to carry residues deeper into the wall before outward movement occurs.

State of the Art

Although this technique has not yet been applied to building decontamination, an ethanol/Freon mixture (volatilized in a manner similar to that described here) has been used as a degreasing treatment.

Variations of Idea

Laboratory testing has indicated that beta-propiolactone (BPL) may be an effective vapor-phase agent for the treatment of biologically contaminated enclosed areas. Its effectiveness thus far has been limited to bacterial spores, vegetative cells, viruses, and rickettsiae.

It may be feasible to use supplemental heating (e.g., microwaves) to maintain solvent at the boiling point in the building materials, thereby enhancing solubility of the contaminant.

Applicability

Depending on the choice of solvent, this method has potential for many contaminants of interest and a wide range of building materials.

Effectiveness

If the proper solvent is used, it should remove most or all surface contamination. The primary difficulty is achieving an outward flux of contaminated solvents from porous building materials. Whether this can be accomplished within a realistic period of time is not known. A secondary decontamination treatment may be necessary to remove any residual contaminants not removed by the solvent.

Section 4/Vapor-Phase Solvent Extraction (Method 14)

Engineering Considerations

Building Preparation--

Buildings are sealed to prevent undue release of solvent vapors. Windows may have to be insulated. Pipes and tanks are opened to allow penetration of solvent vapors. Adequate air circulation during the process should be ensured.

Process Description--

Figure 14 presents a flow diagram of the vapor-phase solvent extraction procedure.

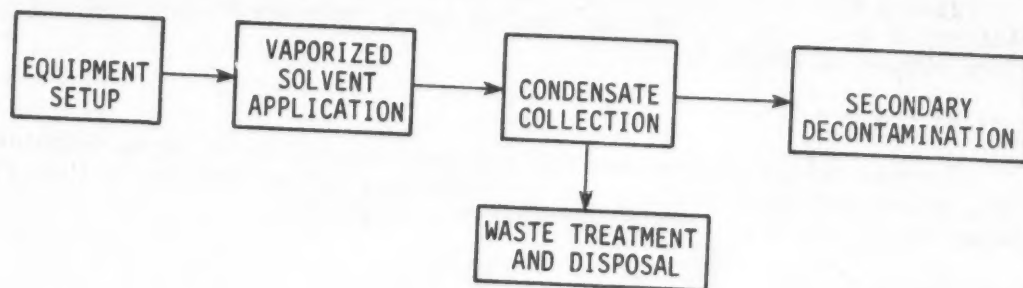


Figure 14. Vapor-phase solvent extraction process flow diagram.

The solvent is vaporized in a boiler external to the building. The vapors enter the building through a series of insulated pipes and vents. The solvent permeates through the building, condensing as it cools below the boiling point. The contaminant-laden liquid solvent is collected in a sump, from which it is pumped to a waste treatment system, where the contaminants are removed. The solvent is then recycled to the boiler. Cleanup entails washing the walls with water or heating to volatilize the residual solvent.

Equipment and Support Facilities Needed--

Pumps, a solvent boiler, and a waste treatment system are needed for this method.

Time Requirements--

Low to moderate setup time is needed for the boiler, ductwork, etc. Personnel time will probably be low to moderate, mainly for setup and tear-down. This method is basically a passive process (only monitors are required during decontamination). Decontamination time depends on the rate of diffusion and the number of applications required (hours to days). Equipment removal requires low to moderate tear-down time. Cleanup time should be low.

Safety Requirements

Process hazards consist of explosion or fire hazards from flammable solvents. The toxicity of the solvents may present a personnel hazard. If a flammable solvent is used, explosion-proof equipment is required. Personnel must wear protective clothing. Adequate air circulation is needed while personnel are in the treated area. Depending on the solvent, respirators may be necessary. See Section 5 for additional worker health and safety requirements.

Waste Disposal

Spent solvent waste from the treatment process may be considered hazardous. Consult 40 CFR Part 261 and appropriate EPA guidance for definitions and listings of hazardous wastes. If the wastes are considered hazardous, they must be treated or disposed of in a RCRA-permitted facility.

Costs

Structural Damage and Repair Costs--

No damage or repair costs are expected.

Treatment and Disposal Costs--

Costs for utilities and fuel should be low to moderate for boiler fuel and pumps. Equipment costs should be low to moderate for the boiler, ductwork, and pumps, depending on the complexity of the solvent recovery/recycle system. Material costs may be moderate to high, depending on the recovery system (i.e., a high cost if solvent cannot be recovered and recycled). Manpower costs should be low to moderate for equipment setup and tear-down, monitoring the boiler, etc., during decontamination. Disposal costs may be moderate to high, depending on whether or not the wastes are considered hazardous.

Future Work

Equipment specifications and process designations (application, recovery, collection, efficiency, solvent selection, temperature, and time) must be made. Experimental testing for this will be required.

Information Sources

The bulk of the information in this subsection came from Reference 20.

ACID ETCHING (METHOD 15)

General Description

Acid is applied to a contaminated surface to promote corrosion and removal of the surface layer. The resulting debris is then neutralized and disposed of. Thermal or chemical treatment of the removed material may be required to destroy the contaminant before disposal. Figure 15 is a schematic diagram of a typical acid etching system.

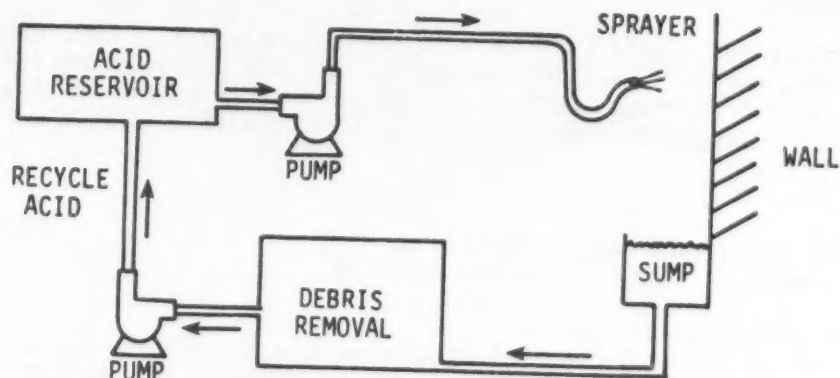


Figure 15. Schematic diagram of the acid etching process.

Advantages

Acid etching may cause decomposition of the contaminant as it is removed from the surface.

Disadvantages

This technique is hazardous and requires special application equipment. Primarily applicable to metals that will readily corrode, this technique requires a large volume of acid.

State of the Art

The effect of acids on various materials is well-established. Muriatic acid (hydrochloric acid) is used to remove dirt and grime from brick building surfaces in urban areas and to clean metal parts (e.g., pickle liquors from metal finishing operations). Hydrofluoric acid is also commonly used to etch window glass. This technique is not known to have been applied to chemically contaminated building surfaces.

Variations of Idea

Acid can be applied as a mixture in steam, or it can be sprayed or brushed on at ambient or elevated temperatures. It can also be applied as a gas (e.g., HCl gas).

Applicability

This method may be applicable to many contaminants. It is applicable primarily to mild steel and wood surfaces; it may be ineffective on other surfaces, such as concrete. Acid etching is only a surface treatment; it is not effective on subsurface contamination of building materials.

Effectiveness

This technique removes contaminants from metal surfaces (e.g., light steel) and wood very effectively and completely. It may also be effective on concrete, brick structures, and some plastic materials. Secondary methods (physical, chemical, and/or thermal) may be required to decontaminate or remove contaminants that have penetrated the surface layer through cracks and pores.

Engineering Considerations

Building Preparation--

Corrosion-resistant paint is removed from equipment and pipes prior to application of the acid.

Process Description--

Acid is spray-applied to the surface and allowed to induce corrosion. The surface is then neutralized and washed with water to remove residual oxide coatings. A secondary decontamination treatment may be required to further remove contaminants from concrete, brick, etc.

Equipment and Support Facilities Needed--

Acid etching requires spraying equipment and a pump, water spraying equipment (hose), an acid source, an acid neutralizer, and a steam source (optional). Available equipment may not be corrosion-resistant; thus, considerable maintenance and periodic replacement will be required.

Time Requirements--

Setup time for paint removal may be required before treatment. Personnel time is required only for spraying and cleanup. The process may be time consuming if all surfaces are treated and if repeated applications are required. Decontamination time may be long because of the slow reaction rate. Equipment removal and tear-down time should not take very long, but cleanup could be lengthy. All the acid must be completely washed off the equipment to avoid further corrosion.

Section 4/Acid Etching (Method 15)

Safety Requirements

Acid skin burns and inhalation of toxic fumes are potential personnel hazards. Personnel protection requires rubber suits, boots, and gloves, and eye and respiratory protection. A safety shower and emergency eyewash should be readily available. See Section 5 for additional worker health and safety requirements.

Waste Disposal

Waste treatment and disposal may be necessary. Insoluble metal oxides and salts require treatment such as filtration. Large amounts of soluble salts must be concentrated before they can be disposed of in a chemical landfill. Low concentrations of some salts (NaCl or Na_2SO_4) can be placed in a city sewer. Decomposed wood can either be incinerated or landfilled.

Costs

Structural Damage and Repair Costs--

This method may weaken structural members, depending on their design, initial thickness, material of construction, and the number of applications of acid. Metal parts will be damaged, and wood may need replacement. Concrete, however, will probably be undamaged. Repair costs should be moderate to high.

Treatment and Disposal Costs--

Costs for utilities and fuel, primarily to power the spraying pump, should be low. Costs for corrosion-resistant equipment should be moderate to high. The kilogram material cost should be low, but a large quantity will be required. Manpower costs, which represent application and cleanup time, should be moderate to high. Waste disposal costs should be moderate. See Appendix C for an analysis of costs associated with the use of this method.

Future Work

The effectiveness of acid removal of contaminants must be established, and any necessary secondary decontamination treatments must be stipulated. Experimental testing for this will be required.

Information Sources

The bulk of the information in this subsection came from Reference 20.

BLEACHING (METHOD 16)

General Description

Bleach formulations are applied to a contaminated surface, allowed to react with contaminants, and removed. Application usually occurs in conjunction with other decontamination efforts, such as the use of absorbents and/or waterwashing.

Advantages

Bleach is an effective decontaminating agent when used against metal surfaces.

Disadvantages

Solid bleach formulations are generally applied as a slurry, which can result in periodic clogging of application equipment. Depending on concentration and composition, bleach slurries may cause corrosion of application equipment and/or the surfaces being treated.

State of the Art

Bleach has been used as a decontaminant against mustard, G and V chemical agents, and (experimentally) organophosphorous pesticides.

Variations of Idea

Various types of bleach formulations have been used as decontaminating agents. Traditionally, calcium hypochlorite has been used, although recently sodium-based bleach formulations have had some application. The various bleaches used include Grades I, II, and III, with >35 percent, 29 to 35 percent, and <29 percent available chlorine, respectively; STB (supertropical bleach), a British formula containing >30 percent available chlorine; HTB (High Test Bleach), which has approximately 42 percent chlorine content; and liquid household bleach (sodium hypochlorite and sodium hydroxide).

Applicability

Bleach is most effective against chemical agents and liquid pesticide spills. Bleach has been used on metal, wood, and concrete surfaces, but it is most effective against metal.

Section 4/Bleaching (Method 16)

Effectiveness

Bleach formulations chemically degrade and detoxify many contaminants, especially pesticides. Chemical degradation rates can be affected by other pre- or post-bleach decontamination efforts.

Bleach formulations are normally used in conjunction with other decontamination techniques, most often as a followup for detoxifying pesticides on surfaces where a physical procedure did not produce satisfactory results (e.g., safe ambient contaminant levels).

Engineering Considerations

Process Description--

The bleach solution is added in generous amounts to the contaminated surface. The surface is scrubbed for 15 to 60 s, allowed to stand for about 15 min, and then flushed thoroughly with water. The bleach application and wash can be repeated a second time if necessary.

Equipment and Support Facilities Needed--

Bleach application and waterwashing equipment (hoses, scrubbers, containers), waste recovery system, and safety equipment are needed. Most equipment is readily available from commercial manufacturers and chemical companies.

Time Requirements--

Decontamination time is low. Although bleach application and chemical detoxification should proceed rather rapidly, contaminated surfaces should be allowed drying time (approximately 5 h).

Safety Requirements

Basic safety requirements that are used when working with chemical agents and pesticides should be adhered to. At a minimum, workers should go through a training program and be equipped with glasses, full-body protective coveralls, impermeable gloves, and foot cover. Additional safety equipment depends on the toxicity of contaminants. See Section 5 for additional worker health and safety requirements.

Waste Disposal

Because application of bleach slurries is usually performed in conjunction with waterwashing, hazardous sludges and liquids may result. A controlled area should be set up so that all waste slurries and liquids can be collected in a sump or other recovery system. The waste materials can then be properly disposed of. Consult 40 CFR Part 261 and appropriate EPA guidance for definitions and listings of hazardous waste. If the wastes are considered hazardous, they must be disposed of in a RCRA-permitted facility.

Costs

Structural Damage and Repair Costs--

Building damage depends on the surface material, contaminants, and supplementary decontamination efforts. Repair costs should be low to moderate.

Treatment and Disposal Costs--

Treatment and disposal costs should be moderate. Bleach supplies, application equipment, and recovery system will constitute most of the costs. Labor costs should be low. See Appendix C for an analysis of costs associated with the use of this method.

Future Work

Work is needed to improve the technique for applying bleach to porous surfaces, and to lessen the corrosive impact of bleach on equipment and building materials.

Information Sources

The bulk of the information in this subsection came from References 19 and 25.

FLAMING (METHOD 17)

General Description

Controlled high temperature flames are applied to noncombustible surfaces to thermally degrade all contaminants.

Advantages

Flaming provides complete and rapid destruction of all residues contacted.

Disadvantages

Flaming is primarily a surface decontamination technique. Subsurface decontamination of building materials may be possible, but extensive damage to the material would probably result. This technique may detonate combustible residues. It also can involve high fuel costs.

State of the Art

Flaming is the state-of-the-art technique for decontaminating building surfaces at explosives installations. The technique has been applied to the decontamination of Frankford Arsenal (see Appendix H).

Variations of Idea

Flaming may either be accomplished by a hand-held flamer or by a remotely operated flamer. The use of a remotely operated flamer is restricted to expansive open surfaces, whereas hand-held flamers are required for complex areas, cracks, etc. Figures 16 and 17 are photographs of a hand-held flamer and a remotely operated wall flamer.

Applicability

The flaming process is applicable to all explosives and some low-level radioactive contaminants. Its applicability to other contaminants is not well known. This technique is applicable to painted and unpainted concrete, cement, brick, and metals.

Effectiveness

The contaminants thermally decompose to volatile products by combination ring-splitting or fragmentation. In all cases, the reaction is exothermic and autocatalytic. Complete decomposition of all contaminant residues that are near the flame front should be accomplished because of the intensity of the heat and the action of free radicals developed by the flame.

The adsorption of the contaminant on a particular substrate may inhibit the decomposition reaction; however, this effect is expected to be small, and it is believed that complete destruction of contaminants on surfaces can be achieved.

Engineering Considerations

Building Preparation--

Combustible materials (e.g., wood and plastic) and friable materials (e.g., asbestos and transite) are removed prior to flaming operations. To achieve complete surface decontamination, all areas must be accessible to the flame front; thus, obstructions to the flame must be removed. Heat conduction to inaccessible areas is dependent on the building material and flame dwell time.

Process Description--

Figure 18 presents a flow diagram of the flaming process. If a building has large, open, continuous surface areas, a remotely operated flamer is preferred. Otherwise, a hand-held flamer is preferred.

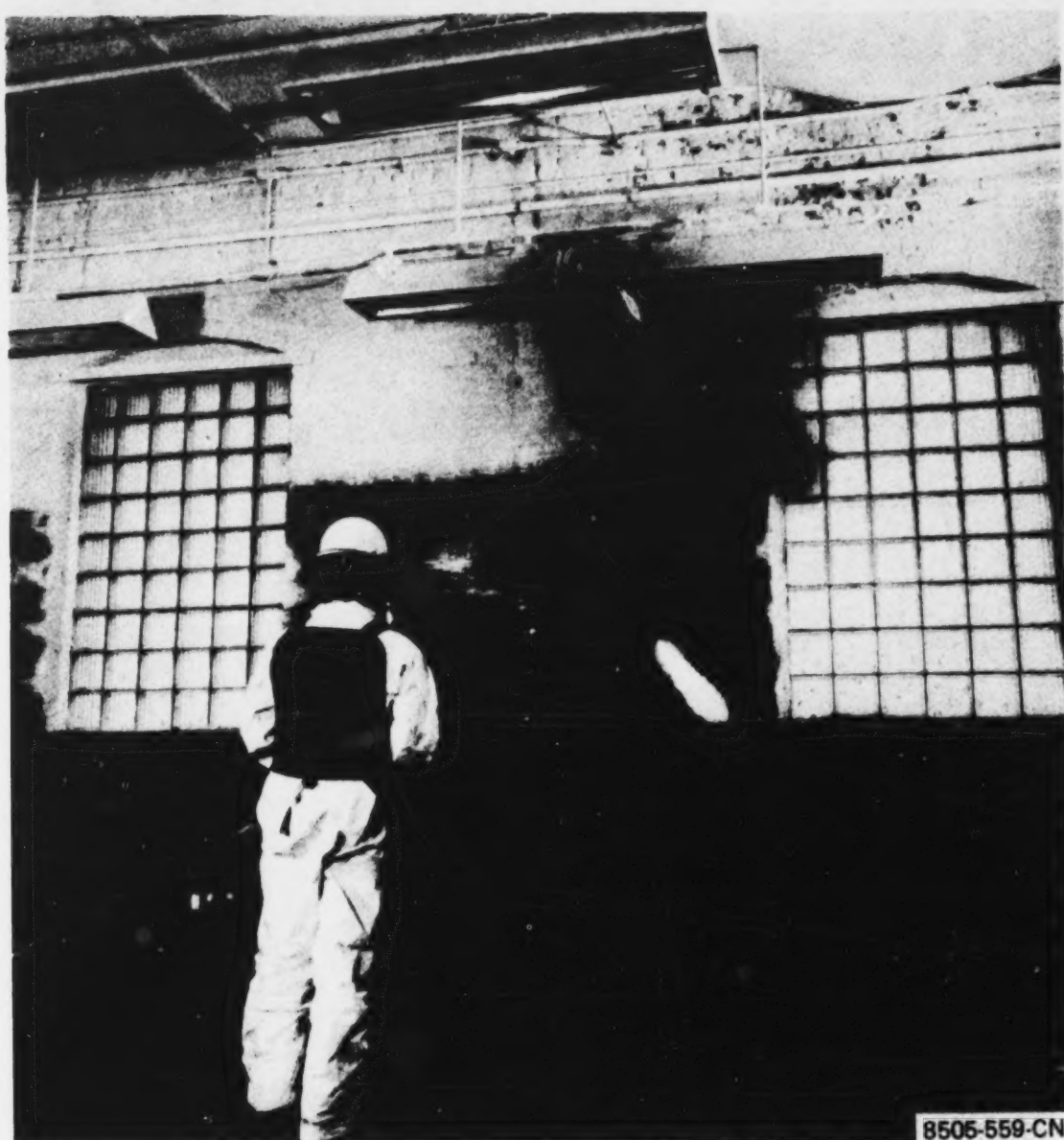


Figure 16. Hand flamer.

Source: Reference 20.

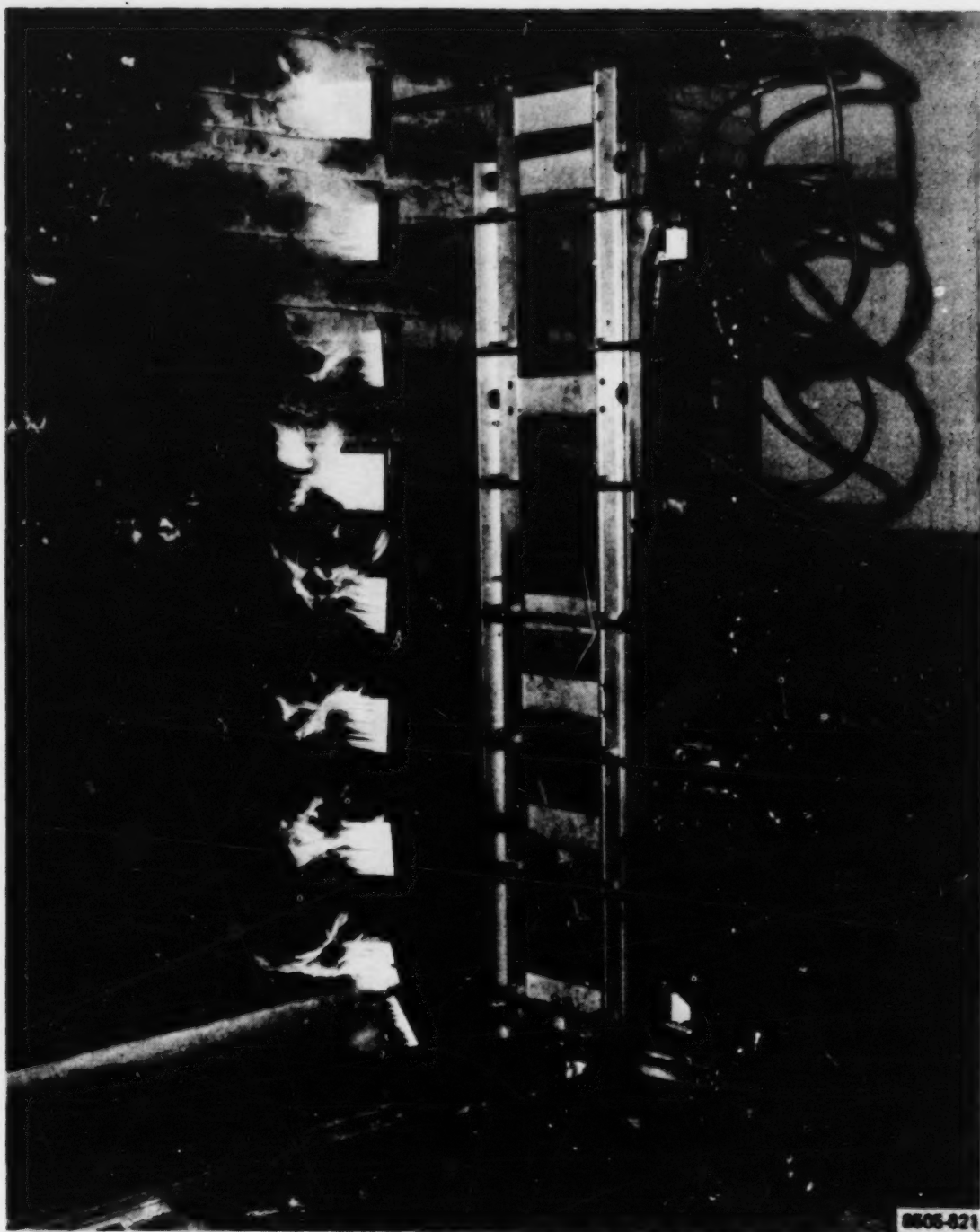


Figure 17. Remotely operated wall flamer.

Source: Reference 20.

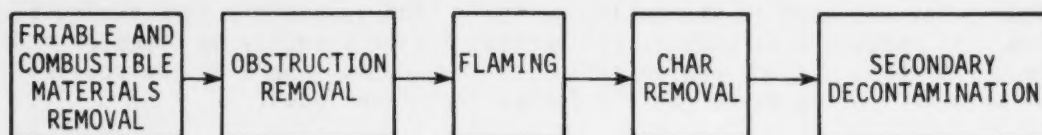


Figure 18. Flaming process flow diagram.

Because of the high temperature of the flame, its dwell time is held to a minimum to minimize material damage. If subsurface decontamination of building materials is required, the dwell time of the flame can approach 10 min or longer (time is dependent on material). This can cause excessive damage to the building materials. The requirements for a supplemental treatment depend on both the depth of contamination and thermal penetration.

Removal and cleanup of surface paint char may be required prior to repainting. Washdown of concrete may be advantageous to allow it to regain its strength.

Equipment and Support Facilities Needed--

This technique requires a torch (hand-held or remotely operated), fuel source, hoses, regulators, fire extinguishers, and tools to remove obstructions and combustible material.

Time Requirements--

The setup time depends on the number of obstructions and the amount of combustible materials that must be removed prior to flaming.

Personnel time is long if a hand-held flamer is used extensively, and short if a remotely operated flamer is used. Surface decontamination time is very short. At the Frankford Arsenal, a remotely operated flamer was used along the walls at a rate of 3m/min. For niches and cracks, a 2-min dwell time is suggested for decontamination. For subsurface treatment, decontamination time increases greatly. To achieve a thermal penetration of 300°C at a depth of 5 cm requires dwell times of 16 min for concrete and 25 min for brick.

No tear-down time is needed for equipment removal if only a hand-held flamer is used; otherwise, moderate time is needed. Removal of char from the wall will not require much cleanup time.

Safety Requirements

Thermal decomposition of contaminants may produce gaseous pollutant hazards that would require scrubbing to prevent release to the atmosphere. If

Section 4/Flaming (Method 17)

lead paint was used in the building, toxic lead vapors may form during flaming. If combustible residues are heated, either directly by flame or indirectly by heat conduction, an explosion may occur. There is the possibility of personnel being burned by the flames or hot surfaces.

Shielding, safety glasses, fire extinguishers, nonstatic clothing, respirators, and remotely operated equipment may be employed as protective methods to reduce potential safety hazards. Local exhaust hoods may be used to vent gases and collect lead vapors. See Section 5 for additional worker health and safety requirements.

Waste Disposal

The wastes or debris generated by flaming (char) may be considered hazardous. Consult 40 CFR Part 261 and appropriate EPA guidance for definitions and listings of hazardous waste. If the wastes are considered hazardous, they must be disposed of in a RCRA-permitted facility.

Costs

Structural Damage and Repair Costs--

Building damage is expected to be minimal if flaming is used only as a surface decontamination technique; otherwise, damage is expected to be extensive.

Treatment and Disposal Costs--

Costs for utilities and fuel may be high, as flaming requires a large supply of gas (propane or acetylene and either oxygen or air). Equipment costs will be moderate. Hand-held flamers are off-the-shelf equipment. Remotely operated flamers can be modeled after the design used at Frankford Arsenal. No material costs should be encountered unless repainting is required. Manpower costs may be high, as flaming is labor-intensive, especially if hand-held flaming is performed to a large extent.

If a structure is ultimately to be torn down, this treatment may mean the difference in costs between disposing of the debris in a hazardous waste landfill versus a solid waste landfill. Such a cost differential could be substantial. See Appendix C for an analysis of costs associated with the use of this method.

Future Work

More information is needed on the selection of a secondary treatment if surface flaming is performed. In any case, concentration gradients of contaminants in building materials must be determined. Experimental testing for this will be required.

Information Sources

The bulk of the information in this subsection came from Reference 20. Use of this method is illustrated in the case study presented in Appendix H.

DRILLING AND SPALLING (METHOD 18)

General Description

The drilling and spalling technique can remove up to 5 cm of surface from concrete or similar materials. This technique consists of drilling holes (2.5 to 4 cm diameter) approximately 7.5 cm deep. The spalling tool bit is inserted into the hole and hydraulically spreads to spall off the contaminated concrete. Figure 19 is a photograph of a drilling and spalling rig. Figure 20 is a sketch of a concrete spaller.

Advantages

The technique can achieve deeper penetration (removal) of surfaces than other surface-removal techniques. It is good for large-scale application.

Disadvantages

The treated surface is very rough and coarse and may require resurfacing (i.e., capping with concrete). Rebars may be exposed. Substantial amounts of contaminated debris are generated.

State of the Art

The drilling and spalling method has been used in the decommissioning of nuclear facilities. A drilling and spalling rig is being designed and tested by Battelle Pacific Northwest Laboratories to increase the concrete removal rate.

Variations of Idea

Vacuum filter systems and water sprayers can be used to control dust during drilling and spalling operations. A remotely operated drill and spall rig may also be used.

Applicability

Drilling and spalling is applicable to concrete only (not to concrete block). This technique is not suitable for hard-to-reach areas such as behind pipes and equipment. Its applicability depends on interior building configuration. It should be useful in removing all types of contaminants, with the



Figure 19. Drilling and spalling rig.

Source: Reference 21.

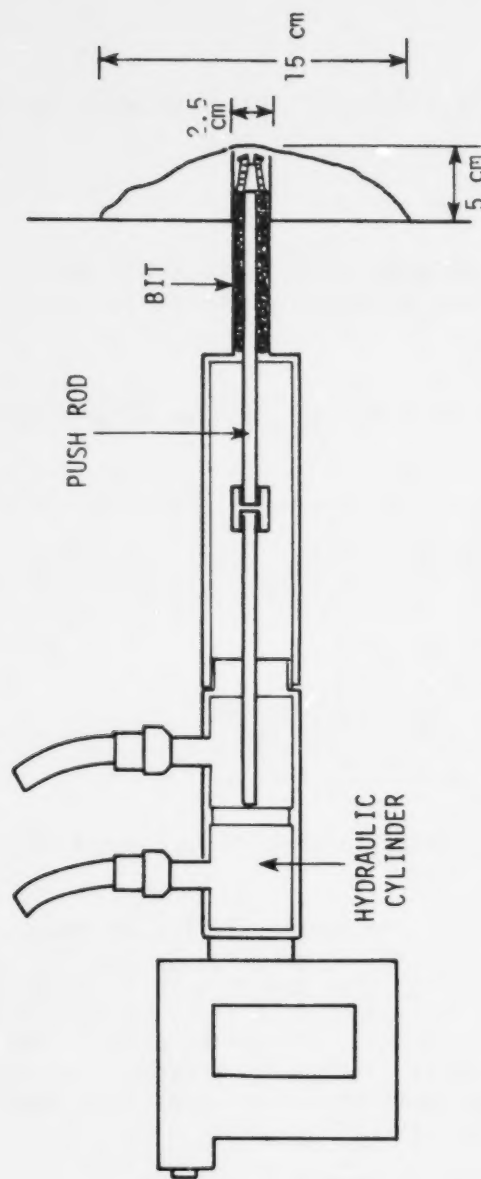


Figure 20. Concrete spaller.

Source: Reference 20.

Section 4/Drilling and Spalling (Method 18)

exception of highly toxic residues of primary explosives such as lead azide and lead styphnate.

Effectiveness

Complete removal can be obtained for contamination up to 5 cm deep in concrete.

Engineering Considerations

Building Preparation--

Building preparation involves removing obstructions to the drilling and spalling rig and assuring that pockets of combustible residues are not present.

Process Description--

A flow diagram of the drilling and spalling decontamination method is presented in Figure 21.

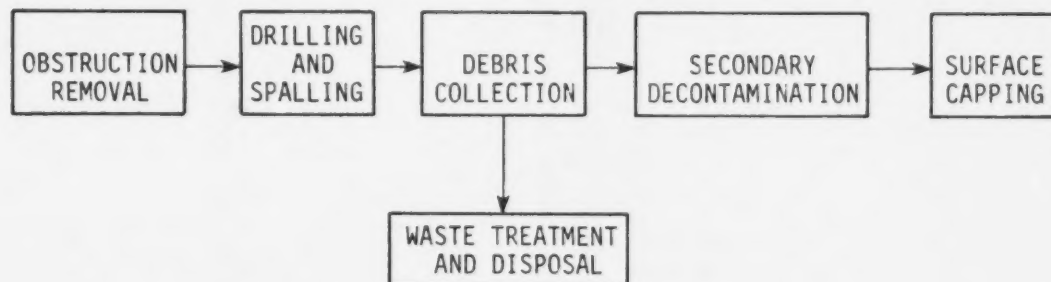


Figure 21. Drilling and spalling process flow diagram.

Holes to 4 cm in diameter, approximately 7.5 cm deep, and 30 cm apart are drilled into the concrete surface. Hydraulically operated spalling tools are inserted into the holes; the spalling tool bit is an expansible tube of the same diameter as the hole. A tapered Mandril is hydraulically forced into the hole to spread the fingers and spall off the concrete. The removed concrete is collected and, if necessary, a secondary treatment is then performed to remove any remaining contaminants that have penetrated deeper than 5 cm. Surface capping is performed last.

Equipment and Support Facilities Needed--

A drilling and spalling rig, a scaffolding/hydraulic positioning system, and cleanup equipment are required.

Time Requirements--

Minimal setup time is required as scaffolding will have to be assembled for wall treatment. Any obstructions must be removed.

Personnel time is extensive because this is a relatively slow process. A remote control device may decrease labor time, but it may not be cost-effective. Battelle Pacific Northwest reports that its drilling and spalling rig has an average removal rate of 6 m³/h for standard concrete. Decontamination time is expected to be extensive because of the slow process and the requirement for secondary treatment.

Equipment removal entails minimal tear-down time, but cleanup time is extensive. Large quantities of concrete will have to be collected, and surfaces may require washdown.

Safety Requirements

High dust and noise levels, high-pressure air lines, and flying debris may present personnel hazards. Debris and dust may be contaminated. Eye and ear protection and protective clothing should be worn. A dust-suppression system (such as periodic wash-down) may be required. See Section 5 for additional worker health and safety requirements.

Waste Disposal

Contaminated debris must be collected and held for treatment (e.g., incineration) and for disposal. It may require management as a hazardous waste. Consult 40 CFR Part 261 and appropriate EPA guidance for definitions and listings of hazardous waste. If the waste is considered hazardous, it must be disposed of in a RCRA-permitted facility.

Costs

Structural Damage and Repair Costs--

The spalled surface is very rough and will require concrete capping or some other treatment to yield smooth surfaces. Cost is expected to be moderate.

Treatment and Disposal Costs--

Costs for utilities and fuel should be low to moderate. Major equipment costs will be for the drilling and spalling apparatus. A drilling and spalling rig (without positioning equipment) costs approximately \$10,000 (1980 dollars). Material costs for the concrete cap are expected to be low. Manpower costs will be high, as the concrete-removal rate is relatively slow and cleanup time is high. Disposal costs will range from moderate to high, depending on whether or not the debris must be disposed of as a hazardous waste. See Appendix C for an analysis of costs associated with the use of this method.

Section 4/K-20 Sealant (Method 19)

Future Work

Techniques for treating contaminated concrete are needed. Dust control systems need to be designed. The drilling and spalling technique will have to be modified or another technique chosen to decontaminate block, brick, wood, and other building materials. More information is needed to select secondary treatment.

Information Sources

The bulk of the information in this subsection came from References 20 and 21.

K-20 SEALANT (METHOD 19)

General Description

Sealing is the application of a material that penetrates a porous surface and immobilizes contaminants in place. One example of a sealant is a newly developed commercial product, K-20.* This material, which was originally developed as a waterproofing agent, is now being marketed as a building decontaminant. The manufacturer claims that the product is nontoxic, noncorrosive, nonvolatile, and odorless, and contains at least eight chemicals.

K-20 acts by bonding with contaminants and carrying the residue deeper as it penetrates the structural material. K-20 can penetrate most porous materials up to 4 cm.

Although it is believed to act more like a barrier than a detoxifier, manufacturer evidence indicates K-20 may facilitate chemical degradation as well as physical separation of some contaminants. Testing performed for the manufacturer by a private laboratory over a period of approximately 8 mo has indicated incomplete recovery of a known amount of applied contaminant, which indicates possible chemical interaction.

Advantages

Contaminants are stabilized in situ. No hazardous wastes are generated.

Disadvantages

The effectiveness and applicability of K-20 to various contaminants and structural materials have not been verified.

* Lopat Enterprises, Inc., Wanamassa, New Jersey.

State of the Art

K-20 has been used on a PCB-contaminated office building and duct system, an oil spill (liquid PCB's) that occurred on a Navy vessel, and a chlordane-contaminated house.

Variations of Idea

K-20 may be applied to contaminated surfaces by painting or by spraying.

Applicability

K-20 has been used against PCB's and chlordane. It may be effective against lead, asbestos, and dioxins. Additional testing of the product is expected some time in 1984. K-20 has been used on cinders, concrete, tile, brick, marble, and other porous materials.

Effectiveness

The effectiveness of this product as a permanent barrier has not yet been established.

Engineering Considerations

Process Description--

The application process described by the manufacturer is very simple. First, all loose dirt and debris are wiped off the surface to be treated. The K-20 mixture is applied to large open areas by painting with a brush or roller, and to small irregular areas (inside heating ducts, behind pipes and fixtures) by spraying with a low-pressure spray gun. A second coating may follow 24 h later. When the final coat has been applied, time must be allowed for the mixture to thoroughly dry.

Equipment and Support Facilities Needed--

The following equipment and supplies are needed: brushes, brooms, and other equipment to remove excess surface debris; a container for mixing the sealant; a paint brush, roller, or spray gun, and (possibly) a drop cloth; and safety equipment. All equipment can readily be obtained from commercial manufacturers.

Time Requirements--

The time required for removal of loose surface debris, application of K-20, and drying (longest part of the process) should be moderate.

Safety Requirements

Safety requirements have not yet been documented for this product. The eight ingredients contained in K-20 have not been disclosed by the manufacturer; the toxicity of the product is not known. At a minimum, workers should

Section 4/Microbial Degradation (Method 20)

go through a training program and be equipped with eye protection, respirators, full-body protective coveralls, and foot cover. Showers are recommended at the end of the day. See Section 5 for additional worker health and safety requirements.

Waste Disposal

With the exception of the removed surface debris, little or no wastes are expected to be generated. The debris may be contaminated and require management as a hazardous waste. Consult 40 CFR Part 261 and appropriate EPA guidance for definitions and listings of hazardous waste. If the debris is considered hazardous, it must be disposed of in a RCRA-permitted facility.

Costs

Structural Damage and Repair Costs--

No structural damage or repair costs are anticipated.

Treatment and Disposal Costs--

Costs should be moderate for equipment and low to moderate for labor. Most of the cost will be for the sealant mixture. Disposal costs will be relatively low due to the low volumes of wastes generated.

Future Work

Because sealants such as K-20 are new and innovative decontamination techniques, additional data substantiating their effectiveness on various contaminants and materials are needed. Also, the method must stand the test of time (as of May 1984, the longest period between application of K-20 and contaminant testing had been 203 days).

Information Sources

The bulk of the information in this subsection came from Reference 26; personal communication from V. Rose, Pacific Gas and Electric Company, San Francisco, California, April 17, 1984, and May 22, 1984; and personal communication from D. R. Lincoln and L. Flax, Lopat Enterprises, Inc., Asbury Park, New Jersey, December 1983 and February 1984. Use of this method is illustrated in the case study presented in Appendix G.

MICROBIAL DEGRADATION (METHOD 20)

General Description

Contaminants are biologically decomposed by microbes capable of utilizing the contaminant as a nutrient source. Microbes are applied to the contaminated area in an aqueous medium and allowed to digest the contaminant over

time. The microbes are then destroyed chemically or thermally and washed away.

Advantages

Microbes are specific to targeted contaminants. Decontamination operations are relatively safe.

Disadvantages

A large development effort is needed to achieve a workable system. Supplementary treatment probably would be required. Carcinogenic compounds have been detected in the biological degradation products of some chemical warfare and explosive contaminants.

State of the Art

This technique has not yet been applied to building and equipment decontamination. Development could take 2 to 3 years of research. Aerobic biodegradation has been successfully applied in lagoon, soil and groundwater cleanups. Contaminants have included gasoline, oil sludges, phenolics, alcohols, acrylates, and solvents. It has also been used to unclog city sewers and clean up oily wastewater in the bilges of the ship Queen Mary. Microbial degradation has been shown to be effective against pesticide contamination in a laboratory situation.

Variations of Idea

Variations include the use of aerobic and anaerobic microbes, and the use of enzymes produced by cultured microbes to degrade contaminants.

Applicability

This method could be useful for the in situ detoxification of hazardous residues on walls and floors and in abandoned process equipment, storage tanks, sumps, piping, etc.

Effectiveness

Data on the effectiveness of microbial degradation as a building decontamination technique is not available.

Engineering Considerations

Building Preparation--

All areas to be treated are saturated with water to thoroughly moisten them and are kept wet throughout the treatment period. Dry spots will not be decontaminated. A saturated gel or thick polyurethane soft foam can be used to keep the surface wet.

Section 4/Microbial Degradation (Method 20)

Process Description--

The microbial solution is applied to the contaminated area with a spray gun, brush, or roller. The microbes are allowed to penetrate and react with the contaminants. After complete reaction, a detergent or solvent wash removes the reaction products and a major portion of the microbes. Drying should result in the destruction of residual microbes; if not, heating or a chemical treatment (such as acid wash or surfactant wash) may be needed to inactivate the microbes. Finally, a wash with fresh solvent may be a necessary secondary decontamination treatment to remove any remaining contaminants or derivatives.

Equipment and Support Facilities Needed--

This technique requires painting equipment (for application), storage and collection tanks, and heaters and/or dehumidifiers (for drying).

Time Requirements--

Setup time should be low. Personnel time required for application to building surfaces should be equivalent to the time required for painting. Decontamination time depends on the kinetics of the microbial reaction and the mass transfer of microbes into porous materials.

Minimal time is required for removal of application equipment. Minimal cleanup is required; a fresh solvent or detergent wash may be sufficient.

Safety Requirements

Contact with microbes could be hazardous to personnel. Protective clothing, eye protection, and respiratory protection (such as a high-efficiency particulate filter mask) should be worn by all workers. See Section 5 for additional worker health and safety requirements.

Waste Disposal

Some degraded contaminants may still be hazardous and require disposal as hazardous wastes. All rinsates/washwaters should be properly disposed of. Consult 40 CFR Part 261 and appropriate EPA guidance for definitions and listings of hazardous wastes. If the wastes are considered hazardous, they must be disposed of in a RCRA-permitted facility.

Costs

Structural Damage and Repair Costs--

These costs should be minimal as long as the attack by microbes on the structural material is not appreciable.

Treatment and Disposal Costs--

Costs for utilities and fuel should be minimal. Costs of application equipment should be low, and costs of drying equipment should be moderate.

Cost of the microbes will be the only material cost incurred. Personnel costs should be low (similar to painting cost). Disposal costs could be moderate to high, depending on the volume of wastes generated and their disposition.

Future Work

More information is needed on the optimum type of microbial organisms (aerobic vs. anaerobic, etc.); on product identity, destruction efficiency, and kinetics of specific microbe reactions; and on the effect of microbes on building materials. Large research and development efforts may be required.

Information Sources

The bulk of the information in this subsection came from References 20 and 27.

PHOTOCHEMICAL DEGRADATION (METHOD 21)

General Description

In this process, intense ultraviolet (UV) light is applied to a contaminated surface for some period of time. Photodegradation of the contaminant follows. In recent years, attention has been focused on this method because of its usefulness in degrading chlorinated dioxins (TCDD in particular). Three conditions have been found to be essential for the process to proceed: 1) the ability of the compound to absorb light energy, 2) the availability of light at appropriate wavelengths and intensity, and 3) the presence of a hydrogen donor.

Advantages

Photochemical degradation operations can be relatively simple or scaled-up (accompanied by increased technical efforts). It is inexpensive when sunlight is used as the UV light source.

Disadvantages

Photochemical degradation will not work on contaminants imbedded in dense particulate matter (such as thick carpet or deep soil) because UV light cannot penetrate through these surfaces. Exposure hazards may result from intense UV radiation when sources other than the sun (mercury and xenon-arc lamps) are used; exposure hazards may also result from the use of flammable solvents as hydrogen donors.

State of the Art

Photochemical degradation has been used to decontaminate vegetative and soil surfaces and many inert surfaces.

Variations of Idea

Various UV light sources and hydrogen donors may be used. Possible light sources include the sun and mercury and xenon-arc lamps. Possible hydrogen donors include the majority of organic liquids that have a large proportion of hydrogen atoms and that are not highly UV-absorbing in the same range as the target contaminant; examples are methanol, benzene, glycol, and glycol ethers such as Carbitols and Cellosolves, natural vegetable and mineral oils, furniture polish, and petroleum distillates.

Photochemical degradation has many different potential applications, depending on the nature of the contaminated substrate. These include:

- (1) Use of a portable UV light and hydrogen donor to decontaminate interior surfaces and structures, or initially waterwashing, then applying a hydrogen donor and UV light to the wet residue.
- (2) Destruction of residues in building corners and other hard-to-reach places with a UV laser beam.
- (3) Use of other decontamination techniques (e.g., steam cleaning, waterwashing/hydroblasting, solvent extraction, and vapor-phase solvent extraction) followed by condensate and/or solvent collection and the application of photodegradation techniques to the liquid wastes.
- (4) Spray application of a hydrogen donor to contaminated outside surfaces followed by exposure to the sun.

Applicability

Photochemical degradation should be applicable to a wide range of contaminants, and specific data on the photodegradability of numerous chemicals should be available in the literature. The method has recently been used to degrade dioxin (TCDD) residues in Italy and the United States. Experiments are ongoing to determine the method's usefulness for PCB destruction.

Photochemical degradation is potentially applicable to all surfaces, although best results can be expected on smooth surfaces.

Effectiveness

Photodegradation efficiencies as related to actual building, structure, and equipment decontamination efforts have not been well documented. It is

believed, however, that photodegradation could result in complete in situ elimination of toxic residues on surfaces. Deeply imbedded residues will not be degraded, and a secondary treatment technique may be required.

Engineering Considerations

Building Preparation--

Minimal building preparation is required. Activities may include the application of a hydrogen donor and the setting up of a UV light source (if the sun is not used).

Process Description--

A hydrogen donor is applied to the contaminated surface, which is then exposed to UV light. When used with other methods, surfaces are first treated, and the liquid residues are then decontaminated by adding a contaminant-specific organic solvent, followed by exposure to a UV light source.

Equipment and Support Facilities Needed--

Required equipment includes a hydrogen donor, equipment for application of the hydrogen donor (spray or brush), a UV light source, and additional equipment (as necessary) if other decontamination procedures are implemented.

The hydrogen donor/contaminant match may be hard to establish, as might specific UV light sources for individual decontamination efforts.

Time Requirements--

Decontamination of the area under treatment should be complete within 24 h. Time for total building decontamination may be extensive depending upon size, complexity, and number of light sources used concurrently.

Safety Requirements

Care should be taken in dealing with specific hydrogen donors. Also, personnel must be aware of hazards associated with artificial UV light sources (e.g., eye and skin damage). Protective equipment should be the same as that used in dioxin-contaminated areas. In addition, eye protection should be worn. See Section 5 for additional worker health and safety requirements.

Waste Disposal

Waste treatment and disposal should not be required unless this method is used in conjunction with another decontamination method in which a condensate or liquid solution is generated.

Section 4/Photochemical Degradation (Method 21)

Costs

Structural Damage and Repair Costs--

Ultraviolet light may cause bleaching of fabric surfaces. Replacement costs should be minimal.

Treatment and Disposal Costs--

Treatment costs should be moderate to high depending on size and complexity of the structure. Waste disposal costs should be negligible unless a second decontamination technique is used in conjunction with photochemical degradation.

Future Work

Research is needed for further establishing specific UV light/hydrogen donor/contaminant procedures.

Information Sources

The bulk of the information in this subsection came from References 28, 29, and 30, and personal communication from R. Kimbrough, Centers for Disease Control, Atlanta, Georgia, February 16, 1984.

SECTION 5

WORKER HEALTH AND SAFETY

Ensuring worker health and safety is of primary importance in all decontamination operations. A significant effort must be put into developing procedures and methodologies that will protect workers from the contaminants at Superfund sites. Training, medical surveillance, personal protective equipment, and site safety plans--the key elements necessary to ensure the health and safety of decontamination workers during site operations--are described in this section. These elements should be incorporated into the site decontamination plan described in Section 3.

TRAINING

All personnel who will be engaged in inspection, sampling, or decontamination activities at Superfund emergency or remedial sites should undergo various levels of orientation and training. Hazardous waste training courses can be developed in-house (under the direction of experts in the field), or workers may attend any number of commercial courses available throughout the United States. These commercial courses, which have become very popular in the 1980's, are sponsored by universities, private firms, and local, state and Federal agencies. Every course should have the following basic components: classroom training, hands-on field work, and periodic refresher training.

In the initial classroom training, individuals gain basic familiarity with standard operating procedures, program policies and concepts, protective equipment, toxicology, industrial hygiene considerations, respiratory protection, safety plan development, remedial planning, air characterization, field sampling, chain-of-custody procedures, decontamination procedures, field investigation procedures, and emergency preparedness.³¹

When trainees demonstrate an understanding of the classroom topics, they should participate in hands-on training in a field setting. Among the benefits participants will gain from such training are the experience of putting theory into practice, greater confidence in themselves and in the equipment and techniques upon which they will ultimately rely, and the building of a decontamination "team."

Refresher training courses should be offered every 6 to 12 mo for individuals who will be working in the decontamination field over an extended

Section 5/Medical Surveillance

period of time. These courses should review the basic topics covered in the initial training and inform workers of new regulations affecting their health and safety.

MEDICAL SURVEILLANCE

The purpose of a medical surveillance program is to maintain a record of general worker health to ensure appropriate placement of workers in job categories, to prevent (or to detect at an early stage) any harmful effects of hazardous substances on workers, and to provide resources for emergency medical care and treatment. Responsibility for a medical surveillance program should be assigned to medical personnel that are knowledgeable in toxicology and experienced in occupational medicine. Program development should be coordinated with industrial hygienists, emergency response team members, safety professionals, or other persons involved in the overall site safety plan. Fragmentation of the medical management of employees or of individual medical records should be avoided, however.

Program Components

The major components of a medical surveillance program are preassignment physicals, periodic medical exams, exit exams at employment termination, and emergency medical care plans. Preassignment physicals are performed by a physician prior to the initial placement of an employee in a particular job. The preassignment physical provides a historical record of the worker's previous exposures, shows his or her state of health prior to joining the work force, and collects baseline medical and physiological information for comparison with later health observations. The preassignment physical is particularly important for determining the ability of the employee to wear personal protective equipment and for identifying those individuals who may be hypersusceptible to known hazardous substances at the decontamination site. Detailed elements of a preassignment physical have been described by Roos and Scofield.³²

During the course of decontamination work, periodic medical exams are given at regular intervals to document worker health status, to quantitate biological indicators of exposure, and to provide the earliest possible detection of adverse effects. These exams also provide an excellent opportunity to evaluate the effectiveness of control measures and safety procedures, to correlate environmental monitoring data with medical data, and to refresh hazard awareness training. The frequency and content of periodic medical exams may be designated, in part, by pertinent government regulations. For example, OSHA regulation 29 CFR 1910.1018, Section N, requires the semiannual administration of a sputum cytology test, nasal and skin examination, and chest x-ray for employees with occupational exposures to inorganic arsenic, as well as semiannual documentation of respiratory medical history. Additional OSHA medical surveillance requirements are described in 29 CFR 1910, Subpart Z.

Termination examinations are given at the close of work assignments when the potential for exposure to hazardous substances is past. These exams are desirable because they record health status at the end of exposure and document any health changes that may have occurred during the decontamination project. A typical termination examination should repeat many of the tests that were included in the preassignment physical.

The medical surveillance program must include provisions for emergency medical care and treatment at the decontamination site and at the nearest properly equipped medical facilities. These plans should be based on the hazardous properties of the identified contaminants and on the health and safety risks associated with the actual work operations or equipment. When the potential health effects and injuries have been determined, the appropriate medical materials can be ascertained, obtained, and stocked on site or at the closest medical facility. Methods for obtaining expedient medical attention in an emergency must be established and communicated to all workers. The U.S. EPA Office of Emergency and Remedial Response "Interim Standard Operating Safety Guides," Part 3, suggests specific steps to accomplish this objective.³³

Biological Monitoring

Biological monitoring consists of analytical tests performed on physiological samples such as blood, urine, feces, sputum, exhaled air, and other body fractions to quantitate absorption of specific toxic agents, to detect minor physiological changes, and to diagnose early signs of disease. This type of monitoring should be included in all of the major components of a medical surveillance plan (i.e., preassignment physicals, periodic medical examinations, and termination examinations). Biological monitoring methods should be chosen to reflect potential exposure to the contaminants of concern (when such methods exist) and to maximize worker acceptance.^{34,35} Workers will favor noninvasive tests over invasive, painful, or complicated procedures. Standard test protocols for detecting some chemical contaminants in blood and urine are published by NIOSH in a seven-volume set.⁵⁻⁹ A physician should determine what type of medical monitoring is necessary.

Recordkeeping

Because of the long latent periods between exposure and the appearance of some chronic health effects and the potential legal implications of occupationally related disease, medical records should be retained for a minimum of 40 years. The medical surveillance requirements in many OSHA regulations state that records should be retained for 40 years or for the duration of employment plus 20 years, whichever is longer. Medical records are best kept as the property of a physician. Prior to the start of work activities, it should be established which pieces of information are to be made available to project management.

PERSONAL PROTECTIVE EQUIPMENT

Proper selection and use of personal protective equipment are crucial to the preservation of worker safety and health. Subpart I of OSHA Regulation 29 CFR 1910 states that "protective equipment...shall be provided, used, and maintained...wherever it is necessary by reason of hazards of processes or environment." Personal protective equipment is often the sole barrier separating workers from potentially hazardous substances during decontamination projects. Headgear, protective clothing, gloves, boots, goggles, and respirators are designed to permit safe work operations by preventing skin contact, dermal absorption, inhalation, and inadvertent ingestion of potentially toxic agents. Personal protective equipment is also designed to protect the worker from physical injuries such as eye wounds, bruises, abrasions, and lacerations. Four factors must be considered in the development of a program of personal protective equipment: 1) selection of appropriate equipment, 2) equipment distribution, 3) worker training, and 4) equipment decontamination and/or disposal procedures. Any personal protective equipment program should also meet the general requirements outlined by OSHA 29 CFR 1910, Subpart I.

Equipment Selection

The hazards present at the decontamination site must be characterized before the proper personal protective equipment can be selected. The types, toxicity, and concentrations of contaminants must be defined. Points of potential high-risk contact (splashes, high atmospheric concentrations, etc.) during specific job operations should be identified when possible. The degree of hazard at the decontamination site will dictate the level of personal protective equipment required.

The equipment necessary to protect the body against contact with known or anticipated chemical hazards can be divided into four categories, each affording a different level of protection:³³

Level A requires the highest level of respiratory, skin, and eye protection. Level A protective equipment consists of:

- ° Pressure-demand, self-contained breathing apparatus (MSHA/NIOSH approved)
- ° Fully encapsulating chemical-resistant suit
- ° Coveralls*
- ° Long cotton underwear*
- ° Gloves (outer), chemical-resistant

* Optional.

- ° Gloves (inner), chemical-resistant
- ° Boots, chemical-resistant, steel toe and shank (depending on suit construction, worn over or under suit boot)
- ° Hard hat* (under suit)
- ° Disposable protective suit, gloves and boots* (over fully encapsulating suit)
- ° 2-Way radio communications (intrinsically safe)

Level B is selected when the highest level of respiratory protection is needed but a lesser level of skin protection is sufficient. It consists of:

- ° Pressure-demand, self-contained breathing apparatus (MSHA/NIOSH-approved)
- ° Chemical-resistant clothing (overalls and long-sleeved jacket; coveralls; hooded, one- or two-piece chemical-splash suit; disposable chemical-resistant coveralls)
- ° Coveralls*
- ° Gloves (outer), chemical-resistant
- ° Gloves (inner), chemical-resistant
- ° Boots (outer), chemical-resistant, steel toe and shank
- ° Boots (outer), chemical-resistant (disposable)*
- ° Hard hat (face shield*)
- ° 2-Way radio communications (intrinsically safe)

Level C is selected when the type of airborne substances are known and the criteria for air purifying respirators are met. Level C protective equipment consists of:

- ° Full-face, air-purifying, canister-equipped respirator (MSHA/NIOSH-approved)
- ° Chemical-resistant clothing (coveralls; hooded, two-piece chemical-splash suit; chemical-resistant hood and apron; disposable chemical-resistant coveralls)

* Optional.

Section 5/Personal Protective Equipment

- Coveralls*
- Gloves (outer), chemical-resistant
- Gloves (inner), chemical-resistant*
- Boots (outer), chemical-resistant, steel toe and shank*
- Boots (outer), chemical-resistant (disposable)*
- Hard hat (face shield*)
- Escape mask*
- 2-Way radio communications (intrinsically safe)

Level D is selected when there are no respiratory or skin hazards.

Level D protective equipment consists of:

- Coveralls
- Gloves*
- Boots/shoes, leather or chemical-resistant, steel toe and shank
- Boots (outer), chemical-resistant (disposable)*
- Safety glasses or chemical-splash goggles*
- Hard hat (face shield*)
- Escape mask*

The level of protective equipment chosen should be able to handle the highest exposure conditions likely to be encountered during the scope of work. Level B protection is the minimum level recommended on initial site entries until the hazards are further defined. Level C protection is adequate for most decontamination operations. Personal protective equipment requirements for some chemicals are designated by government regulations. For example, the OSHA Asbestos Regulation (29 CFR 1910.1001) describes the types of respirators that must be used by workers occupationally exposed to asbestos fibers.

Specific details about equipment performance characteristics are available from manufacturers of personal protective equipment. In addition, several guides published by NIOSH describe types of personal protective equipment (including respirators) and their appropriate uses.³⁶⁻³⁸

* Optional.

Equipment Distribution

For effective management of a personal protective equipment program, one particular location or locations should be established as a center for all equipment distribution, storage, repair, and maintenance. The responsibility for these activities should be assigned to a specific individual or group of individuals. All personnel should be made aware of the location of the personal protective equipment center. Checkout procedures for some safety devices, such as self-contained breathing apparatuses (SCBA), may be useful to track particularly hazardous operations. Extra equipment should be readily available in case of emergency or for use by site visitors.

Training

All personnel who will regularly work in contaminated areas, those who might enter contaminated areas in unusual circumstances, and visitors must be instructed in the proper use of the personal protective equipment. The topics covered in this training should include the nature of the hazard the personal protective equipment is designed to prevent; the proper use and limitations of the protective device; and cleaning, daily inspection, and routine maintenance of the equipment.

Equipment Decontamination and Disposal

During use, personal protective equipment is subject to physical damage as well as contamination with hazardous substances. Contamination must be removed from equipment prior to its reuse. If equipment is washed, the spent wash and rinse solutions are treated as contaminated waste. Damaged or non-reusable equipment also should be disposed of as contaminated waste. General guidelines for decontamination of personal protective equipment are presented in Part 7 of the "Interim Status Operating Safety Guides."³³

SITE SAFETY PLAN

The objective of a site safety plan is the establishment of standard operating procedures and guidelines to ensure that all facets of the decontamination operation are conducted in a safe and orderly manner. Depending on the situation, the responsibility for developing a site safety plan may lie with Federal agencies (OSHA, NIOSH), state agencies (mainly Departments of Health), site owners, or cleanup contractors. Because safety plans must be site-specific, they are subject to modifications by onsite supervisory personnel.

The site safety plan should appoint one individual as the site safety officer. This individual should be thoroughly knowledgeable of all Federal, state, and local governmental regulations and guidelines pertaining to the contaminant(s) at the site. The site safety officer may consider consulting

Section 5/ Site Safety Plan

other references (industry-wide publications, private research documents, industrial hygiene organizations) that address the specific contaminants of concern. The site safety officer should be given complete control of the safety aspects of the cleanup operations and should have the authority to make on-the-spot decisions concerning job safety procedures. In addition, the safety officer should be responsible for reporting, documenting, and correcting any infractions of safety-related rules and should have the authority to shut down the job site if severe and/or chronic rule infractions occur.

Within the organization responsible for overall cleanup operations, a QA/QC staff responsible for the monitoring of all site safety activities should be established. As part of their duties, QA/QC personnel should review the site safety plan before its implementation and follow up with periodic audits to assure compliance with the previously approved procedures.

The site safety plan should focus on the standard operating procedures necessary to ensure that all field work is conducted in an efficient yet safe manner. When a decontamination operation has been contractually agreed upon, an extensive review and investigation of the job site should be conducted before any field operations are begun. During this time, site safety personnel should familiarize themselves with the layout of the cleanup area and become thoroughly knowledgeable of the job specifications for the project, particularly those affecting worker health and safety.

In addition to an investigation of the job site, preoperational activities should include obtaining, verifying, and posting emergency phone numbers (fire department, hospitals, security); compiling a list of the type, amount, and toxicity of wastes and potentially harmful substances found at the site; making sure an eyewash unit is available at the site; obtaining a first aid kit suitable for treating minor injuries that are likely to occur during cleanup operations; ensuring that all personnel who are to work at the site have had the required medical tests and training; notifying all applicable local, state, and Federal agencies; ensuring that all workers have been briefed on the hazards of the contaminant(s) they are about to encounter and are aware of the proper way to carry out decontamination procedures; and maintaining an appropriate supply of protective equipment on site.

When the initial safety precautions have been implemented, containment barriers should be constructed to separate contaminated areas from clean areas. An entry module, which provides for the safe entry and exit of those who must enter and leave contaminated areas, usually takes one of two forms: an airlock or a trailer. Airlocks, which can be constructed on site, consist of prefabricated wooden structures and polyethylene sheeting. Whether a portable trailer with airtight connections or an airlock structure is used, the components are similar and provide like services. Both should include showers, locker areas, rest rooms, security offices, negative air filtration systems, waste disposal operations, and a monitoring and recording station.

Table 4 has been prepared to assist planners and site safety personnel in identifying potential health and safety hazards associated with the use of various cleanup methods. The table lists process-related hazards only. Additional hazards posed by the contaminant(s) being treated or by the structural integrity of the building, structure, or equipment must also be taken into consideration on a case-by-case basis.

TABLE 4. SUMMARY OF POTENTIAL HEALTH AND SAFETY HAZARDS RELATED TO THE USE OF VARIOUS DECONTAMINATION METHODS

Method	Potential Health and Safety Hazards										Comments
	Inhalation ^a	Skin hazard ^c	Noise hazard ^d	Hand/arm vibration hazard ^e	Heat stress hazard ^f	Ultraviolet radiation hazard ^g	Electrical hazard ^h	Biohazard ⁱ	Fire/explosion hazard ^j	Physical contact hazard ^k	
1. Asbestos abatement (removal, encapsulation, enclosure, special operations)	F, V				X		X				Electrical shock hazard from the use of water (for wetting) in proximity to electrical equipment; potential inhalation hazard if vapors from sealants are toxic.
2. Absorption	V	X		X				X			Indicated hazards are associated with the contaminant(s) being cleaned up, not with the sorbent.
3. Demolition	P		X	X				X	X		Fire and explosion hazard if the building is highly contaminated with combustible, explosive, or reactive residues.
4. Dismantling	P		X	X	X			X	X		Fire and explosion hazard if spark-proof tools are not used when dismantling equipment or structures contaminated by combustibles; UV radiation hazard from cutting torches.
5. Dusting/vacuuming/wiping	P			X							Skin hazard from epoxy resins in the uncured state.
6. Encapsulation/enclosure	V	X		X	X			X	X		Fire and explosion hazard if combustible material is gritblasted.
7. Gritblasting	P		X	X	X						Physical contact hazard from high-pressure water lines.
8. Hydroblasting/water-washing			X	X		X					Inhalation, skin, and fire hazards from paint removers containing flammable and/or toxic solvents.
9. Painting/coating (lead-based paint removal, fixative/stabilizer coatings, strippable coatings)	V	X		X				X			Fire and explosion hazard if combustible material is scarified.
10. Scarification	P		X	X				X	X		

(continued)

Table 4 (continued)

Method	Potential Health and Safety Hazards										Comments
	Inhalation ^b	Skin hazard ^c	Noise hazard ^c	Hand/arm vibration hazard ^c	Heat stress hazard ^c	Ultraviolet radiation hazard ^c	Electrical hazard ^c	Biohazard ^c	Fire/explosion hazard ^c	Physical contact hazard ^f	
11. RadKleen	V	X									Inhalation and skin hazards from the use of Freon 113.
12. Solvent washing	V	X						X			Inhalation, skin, and fire hazards from the use of flammable and/or toxic solvents.
13. Steam cleaning	V	X		X							Inhalation and skin hazards from the use of toxic solvent/steam mixtures; possible steam burns.
14. Vapor-phase solvent extraction	V	X						X			Inhalation, skin, and fire hazards from the use of flammable and/or toxic solvents.
15. Acid etching	V	X									Skin hazards from bleaching agents, which are strong oxidizers; oxidizing agents in contact with organic materials can result in the production of heat and toxic gases.
16. Bleaching	V	X									Inhalation hazard from thermal decomposition products; skin hazard (burns) from contact with flames or hot surfaces.
17. Flaming	V,P	X	X	X				X			Fire and explosion hazard if pockets of combustible material are contacted.
18. Drilling and spalling	P		X	X				X		X	Hazards associated with K-20 are uncertain; neither the ingredients nor the results of toxicity tests have been disclosed by the manufacturer.
19. K-20 sealant	V	X		X							

(continued)

Table 4 (continued)

Potential Health and Safety Hazards										
Method	Inhalation ^a	Skin hazard ^b	Noise hazard ^c	Hand/arm vibration hazard ^d	Heat stress hazard ^e	Ultraviolet radiation hazard ^f	Electrical hazard ^g	Biohazard ^h	Fire/explosion hazard ⁱ	Physical contact hazard ^j
20. Microbial degradation	V, P							X		
21. Photochemical degradation	V	X				X				
Comments										
Inhalation hazard from microbes and biological degradation products.										
Eye and skin hazards from the use of artificial UV light sources; inhalation and skin hazards from the use of toxic hydrogen donors.										

- ^a This table presents process-related hazards only. Additional hazards posed by the contaminant(s) being treated or by the structural integrity of the building, structure, or equipment must also be taken into consideration on a case-by-case basis.
- ^b Inhalation hazards include pulmonary deposition or absorption of toxic or nuisance particulates (P), carcinogenic asbestos fibers (F), or toxic chemical vapors (V).
- ^c Skin hazards include dermatoses, chemical burns, percutaneous absorption of chemicals, etc.
- ^d Ultraviolet radiation is both a skin and eye hazard.
- ^e Biohazard is a hazard directly due to a living organism, or the byproduct of a living organism.
- ^f Physical contact hazards include lacerations, injuries to the eye from flying particulate, strains, sprains, impacts, etc.

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APPENDIX A
SUPERFUND SITE SURVEY

In the fall of 1983, a telephone survey was conducted of the decontamination activities at 50 selected Superfund sites across the country. Sites were chosen for the survey based on information indicating that contaminated buildings, structures, or equipment may have been present. The results of the survey are summarized in Table A-1. In many cases, buildings and structures were not present or, if present, were not contaminated; thus, no decontamination activities were planned at these sites. Decontamination activities (planned, in progress, or completed) at sites with contaminated buildings, structures, and equipment are detailed in site data summary forms that follow the summary table. The information obtained through this survey was often sketchy, and as a result, the site data summary forms are often incomplete.

TABLE A-1. SURVEY OF DECONTAMINATION ACTIVITIES AT SELECTED SUPERFUND SITES (FALL 1983)

Site/location	Background	Decontamination activities
<u>Region I</u>		
Cannon Engineering Corp. Bridgewater, Massachusetts	The site was used for the storage and incineration of wastes; on-site structures include four process buildings, an office/warehouse, and a thermal oxidizer.	Contamination of buildings has not been determined; tanks were drained; see site data summary form.
PSC Resources Palmer, Massachusetts	The facility, now inactive, reclaimed waste oils from Massachusetts collection points; the property includes two buildings and abuts a residential area.	Buildings are not contaminated.
Silresim Chemical Corp. Lowell, Massachusetts	A chemical waste reclamation facility with buildings and tanks on site; residential areas border the site on three sides.	All surface structures (buildings and tanks) were dismantled or decontaminated and demolished; see site data summary form.
McKin Site Gray, Maine	The site consists of a fenced enclosure, an incinerator, a concrete block building, an asphalt-lined lagoon, several large storage tanks, numerous 55-gallon drums, and other debris.	Tanks were decontaminated, cut up, and taken away; plans for decontaminating floors have not been finalized; buildings will be destroyed; see site data summary form.
Keefe Environmental Services Epping, New Hampshire	Served as a waste bulking and waste transfer station between 1978 and 1981; the site includes two buildings that have been used to store various drummed waste materials and an office building that acted as a laboratory facility for the site while it was active.	Site is under remedial investigation; feasibility study has not been completed.
Ottati and Goss/Kingston Steel Drum Kingston, New Hampshire	Both operations reconditioned and resold used 55-gallon drums; emergency response action contaminated equipment.	Equipment was decontaminated before leaving the site; see site data summary form.
Somersworth Landfill Somersworth, New Hampshire	A municipal landfill with a garage facility.	Garage is not contaminated.
Old Springfield Landfill Springfield, Vermont	A trailer park was built on top of an abandoned landfill.	Groundwater contamination site; work plan for the remedial investigation/feasibility study is being developed.
<u>Region II</u>		
Brick Township Landfill Ocean County, New Jersey	This site is located in a residential area, 50 feet from a group of condominiums and across the street from the proposed site for a school; the site has an old waste incinerator.	Sheds used to store equipment were removed under an order to close.

(continued)

Table A-1 (continued)

Site/location	Background	Decontamination activities
Chemical Control Elizabeth, New Jersey	Left on site were two buildings that were used for the storage of chemicals and pesticides; the site was the scene of a massive fire in April 1980.	Buildings on site were destroyed in the fire; however, buildings across the street were in the path of the plume and had to be decontaminated; see site data summary form.
Ellis Property Evesham Township, New Jersey	At one time a drum recycling operation; the site consists of a large two-story building housing several wash tanks and troughs, a storage area, and three nearby sheds.	Buildings are not contaminated.
M&T Delisa Landfill Asbury Park, New Jersey	A mall was constructed on top of a closed sanitary landfill.	Groundwater contamination site; no plans to decontaminate the mall or pavement.
Mont Clair/Glen Ridge Essex County, New Jersey	Radioactive material used as fill in a residential neighborhood.	The basements of forty homes were ventilated to reduce radon gas to acceptable levels; removal of the soil is anticipated; see site data summary form.
Myers Property Franklin Township, New Jersey	The site, currently used as a private residence, previously contained various types of commercial facilities; solid chemicals are stored in buildings on the site.	Wooden shacks store chemical drums containing asbestos; no testing has been done, but the shacks will probably be torn down.
PJP Landfill Jersey City, New Jersey	An elevated highway runs through the site; tentative plans call for a truck stop, motel, and commercial stores to be built on the property; smoke from fires on the site often interferes with traffic on the skyway, and the leachate is suspected of corroding the bridge supports.	Currently, there are no buildings on site; the landfill is burning underground, and no proposals for construction at the site will be considered until the fire is put out and the site cleaned up.
Syncon Resins South Kearny, New Jersey	An inactive paint, varnish, and resin manufacturing facility; drums are stored in warehouses.	The buildings are not considered an asset to the property and will probably be torn down.
U. S. Radium Corp. Orange, New Jersey	A former radium processing facility located in a highly populated area; seven commercial/industrial buildings are currently on the site.	Suspected as the source of the contaminated fill material at the Mont Clair/Glen Ridge site; buildings are of slab construction, thus radon gas is not confined; no remedial action has been taken.

(continued)

Table A-1 (continued)

Site/location	Background	Decontamination activities
Love Canal Niagara Falls, New York	In the mid to late 1970's, continued periods of high precipitation raised the water table, carrying chemically contaminated leachate to the surface and into contact with basement foundations.	About 300 homes immediately adjacent to the site were demolished; a habitability study is being conducted in the surrounding area where another 500 homes are located; see site data summary form.
Wide Beach Development Brant, New York	Waste oils were sprayed on roads in this development of 66 homes for dust control until 1978.	County sampled dust in homes; no contamination was found.
Juncos Landfill Juncos, Puerto Rico	Thermometers containing mercury were dumped on the site; a new housing development has been built over the landfill.	As yet, there is no evidence of contamination at the homes; sampling is continuing.
<u>Region III</u> Drake Chemical Co. Lock Haven, Pennsylvania	Made chemical intermediates for pesticides and other products during the 1960's and 1970's; closed operations in 1981; the facility is abandoned.	Buildings will be torn down and decontaminated or sent to a secure landfill; feasibility study has not been completed.
Lehigh Electric and Engineering Co. Old Forge, Pennsylvania	Electrical equipment, including transformers and capacitors, are currently stored at the facility; high levels of PCB's have accumulated on the property.	Concrete slabs will be decontaminated; see site data summary form.
<u>Region IV</u> SCRDI Bluff Road Site Columbia, South Carolina	The site of the South Carolina Recycling and Disposal Co. has a central metal-walled building in which salvageable wastes were stored.	Building will be removed upon site closure.
<u>Region V</u> A & F Materials/Greenup Greenup, Illinois	Operations at the site, which began during 1977, were originally intended to reprocess waste oil and sludges from various generators.	Emergency cleanup efforts centered on the waste oil lagoons; a remedial investigation/feasibility study is under way.
LaSalle Electrical Utilities LaSalle, Illinois	A closed factory which used PCB's to manufacture capacitors from the late 1940's until late 1978; waste oils were used for dust control in the parking lot until 1969.	A remedial investigation/feasibility study has not been conducted.
Seymour Recycling Corp. Seymour, Indiana	An abandoned industrial waste reclamation operation located in Freeman Field Industrial Park, about 2 miles from the center of Seymour.	Several buildings are on site that stored tanks and drums, but contamination has not been determined.

(continued)

Table A-1 (continued)

Site/location	Background	Decontamination activities
Wedzeb Enterprises, Inc. Lebanon, Indiana	Owms two warehouse facilities that were used to store capacitors, many containing PCB insulating oils, for subsequent distribution and resale; a fire destroyed one warehouse, and the debris was left on site.	Only rubble remains.
Anderson Development Co. Adrian, Michigan	MBCOA was manufactured from 1971 to March 1979 and is a widespread environmental, residential, and occupational contaminant.	Remedial actions include weekly street sweeping, paving of an adjacent subdivision, cleaning of 253 households, and covering of driveways and parking lots with tar and stone; status of process buildings has not been determined.
Auto Ion Kalamazoo, Michigan	A former plating waste treatment facility; liquid plating wastes and sludges remain on site in three basement areas of a two-story brick building and in an outside concrete-lined lagoon.	Building has been condemned.
Northernair Plating Cadillac, Michigan	An inactive electroplating facility.	Emergency response site; no remedial investigation has been done.
National Lead-Taracorp Site St. Louis Park, Minnesota	NL Industries, Inc., operated a secondary lead smelter from the 1930's until 1979; a portion of the property was sold to Golden Auto Parts, Inc., in the early 1960's and the remainder to Taracorp, Inc., in August 1979; in May 1982 Taracorp permanently closed the smelting plant; Golden Auto Parts is now located over a portion of a large lead slag disposal site.	Buildings will be torn down.
Chem-Dyne Hamilton, Ohio	A chemical waste transfer and storage facility in business since 1974.	Buildings are contaminated; remedial investigation underway; decontamination may be an option; see site data summary form.
Old Mill Rock Creek, Ohio	About 4 years ago, the site owner was involved with a local brine and oil hauling business in an old grain elevator complex consisting of three or four buildings and several silos; the site is close to a school and several houses.	Buildings have no salvage value, but will probably be left on site to be destroyed by a future owner.
Region VI Old Inger Oil Refinery Barrow, Louisiana	The site, now abandoned, reclaimed oil from refinery wastes; a spill in 1978 contaminated a large surface area; a small employee support building is located on the site.	Waste oil lagoons were drained during an emergency action; no extensive decontamination of the building is planned.

(continued)

Table A-1 (continued)

Site/location	Background	Decontamination activities
Bio-Ecology Systems, Inc. Grand Prairie, Texas	In June 1972, the site was permitted for incineration, chemical treatment, biological oxidation of wastewaters, and landfill of solids resulting from treatment processes; the site operated through June 1978; small buildings and tanks remain.	Tanks were drained, cleaned, dismantled, and removed; the shack was dismantled and removed as well; see site data summary form.
Triangle Chemical Co. Bridge City, Texas	Produced antifreeze, windshield wash solvent, industrial cleaning compounds, hand cleaners, and brake fluids starting in the early 1970's; in 1981 the company declared bankruptcy and abandoned the facility.	Miscellaneous debris was cleaned out of buildings; decontamination was not considered necessary; the site is fenced.
<u>Region VII</u> Dico Co. Des Moines, Iowa	Used TCE to degrease metal parts, and in the past spread the oily waste from this process to control dust on the property.	Groundwater contamination site; company continues to operate; no building decontamination is considered necessary.
Ellisville Site Ellisville, Missouri	In 1980 a contractor unearthed some buried drums of paint solvents and pesticides while constructing a sewer line; further investigation revealed two other areas where industrial wastes had been buried; a horse arena is on site.	Arena is not contaminated.
Shenandoah Stables Moscow Mills, Missouri	The site became contaminated with dioxin in May 1971 when a waste oil hauler sprayed approximately 2,000 gallons of oil for dust control; in August 1971, the top 6 to 8 inches of contaminated soil was excavated from the area and used as fill material in a new highway.	Remedial investigation/feasibility study is being conducted.
Minker/Stout Imperial, Missouri	In 1971 the Bubbling Springs Ranch Arena became contaminated with dioxin when a waste oil hauler sprayed oil for dust control; in 1973 the lessee of the area excavated some of the dioxin-contaminated soil, which was later used as fill material in two residential areas.	Eleven families are being permanently relocated; furniture, appliances, and personal items will be cleaned according to CDC recommendations.
Quail Run Mobile Manor Gray Summit, Missouri	Soil in this mobile home park is contaminated with dioxin.	Homes will be cleaned; see site data summary form.
<u>Region VIII</u> Denver Radium Site Denver, Colorado	Thirty-five Colorado sites have been identified where radium was processed, refined, or fabricated into various devices or products; of these sites, 31 are located in the metropolitan Denver area and include vacant land, industrial operations, buildings, and public streets; all of these have varying levels of radioactivity due to the residues of the radium industry.	Difficult to characterize because of multiple sites.

(continued)

Table A-1 (continued)

Site/location	Background	Decontamination activities
Sand Creek Industrial Site Commerce City, Colorado	The site is industrially zoned and has supported a high volume of chemical and petroleum production; the site includes the former Oriental Refinery, the 48th and Holly Streets Landfill, the Colorado Organic Chemical Co., acid waste disposal pits used by the L.C. Corp., and several small residences and businesses.	Remedial planning in the infant stages; difficult to characterize because of multiple sites.
Anaconda Smelter Anaconda, Montana	A copper smelter was operated from the late 1800's until September 1980; for the most part, the wastes left on site at closure remain.	Contaminated flue dust is being removed so the buildings can be demolished; see site data summary form.
<u>Region IX</u> Taputimu Farm American Samoa	The site, part of an agricultural experimental farm, consists of a warehouse that has been used for more than 10 years for storage of unused chemicals and pesticides.	Currently developing a record of decision; decontamination of the building has been recommended; see site data summary form.
Mountain View Mobile Home Estates Globe, Arizona	The subdivision is built on graded chrysotile asbestos tailings and is directly adjacent to an active asbestos mill.	Too expensive to decontaminate; families will be relocated; homes will be crushed and buried.
MGM Brakes Cloverdale, California	Between 1965 and 1972 the facility operated casting machines that used hydraulic fluids containing PCB's; these fluids were discharged to the ground on site.	Buildings and equipment have been decontaminated; see site data summary form.
PCB Warehouse Saipan, Northern Mariana Islands	A temporary shelter served as an interim storage facility for approximately 1400 gallons of PCB transformer fluid.	Drums in good condition; no leaks or spills; building not contaminated.
<u>Region X</u> Western Processing Co., Inc. Kent, Washington	A converted military base; principal operations are solvent recovery, acid and caustic neutralization, and heavy metal precipitation.	Remedial investigation/feasibility study has not been completed; buildings probably will not be left standing after cleanup; some tanks may be saved.

Appendix A: Superfund Site Survey

REGION: I

DATE: December 5, 1983

SITE: Cannon Engineering Corp.

CONTACT: Jim Ciriello
EPA Region I
617/223-5775

LOCATION: Bridgewater, Massachusetts

HISTORY OF USE: Storage and incineration of wastes.

WASTES ON SITE: Chlorinated hydrocarbons, arsenic, cadmium, chromium, solvents (methylene, xylene, acetone, MEK). Records are not complete.

DESCRIPTION OF BUILDINGS, STRUCTURES, AND EQUIPMENT ON SITE: Located on site are: four process buildings (thin steel), an office/warehouse, a thermal oxidizer, a brick garage, and several tanks (in and out of the buildings). These structures have some salvage value.

CRITERIA FOR DETERMINING CONTAMINATION: A visual inspection revealed wastes remaining in the tanks. However it has not been determined that the buildings are contaminated. Wipe tests may be done.

METHOD OF DECONTAMINATION: Wastes were pumped out of the tanks, and a marine chemist certified that the tanks were waste-free and gas-free.

EQUIPMENT: Explosimeter.

WORKER PROTECTION:

EVALUATION OF DECONTAMINATION EFFECTIVENESS:

COSTS:

Appendix A: Superfund Site Survey

REGION: I

DATE: December 5, 1983

SITE: Silresim Chemical Corp.

CONTACT: Rick Layton
EPA Region I
617/223-5775

LOCATION: Lowell, Massachusetts

HISTORY OF USE: Originally, the site was a tank farm for home heating oil. Silresim used the existing buildings and tanks for a chemical waste reclamation facility.

WASTES ON SITE: 129 priority pollutants have been detected.

DESCRIPTION OF BUILDINGS, STRUCTURES, AND EQUIPMENT ON SITE: Four single-story cinder block or wood frame buildings with flat roofs built on concrete slabs are on site as well as one corrugated steel building.

Brick and cement block building (lab with garage portals)

- ° 38 ft x 108 ft x 15 ft
- ° 18-in. thick walls
- ° Flat roof made of wood
- ° Sampled 10 ft grids on floors and walls at a height of 3-1/2 ft
- ° No contaminants (volatile)

Wood frame building (lab)

- ° 28 ft x 35 ft x 9 ft
- ° Pitched roof
- ° Wood studded with steel and sheet siding
- ° Wood pilings, wood floor

Prefab steel frame building (boiler building)

- ° 40 ft x 80 ft x 14-1/2 ft
- ° Corrugated aluminum sheet siding and roofing

Perched tank field

- ° 4 steel tanks surrounded by a concrete dike
- ° Steel pump house measuring 15 ft x 25 ft x 7 ft

CRITERIA FOR DETERMINING CONTAMINATION: Swipe test.

METHOD OF DECONTAMINATION: All surface structures were dismantled and taken to a secure landfill or decontaminated with a steam cleaner, demolished, and trucked to a landfill.

EQUIPMENT: Steam cleaner.

WORKER PROTECTION: Varied, level C or D.

Appendix A: Superfund Site Survey

Silresim Chemical Corp. (continued)

EVALUATION OF DECONTAMINATION EFFECTIVENESS: Swipe test.

COSTS: Dismantling - \$700,000.

Contact Paul Clay, NUS, 617/275-2970 for more information.

Appendix A: Superfund Site Survey

REGION: I

DATE: October 3, 1983

SITE: McKin Site

CONTACT: Elliot Thomas
EPA Region I
617/223-1591

LOCATION: Gray, Maine

HISTORY OF USE: A waste processing operation originally constructed, in part, to accommodate waste generated from an oil spill by a Norwegian tanker. The owners also accepted septic tank wastes and industrial process wastes.

WASTES ON SITE: Several organic chemicals.

DESCRIPTION OF BUILDINGS, STRUCTURES, AND EQUIPMENT ON SITE: Concrete block building with concrete floor, approximately 14 ft x 30 ft. Attached to and within the building is an incinerator unit and associated machinery. There are several large storage tanks on site as well.

CRITERIA FOR DETERMINING CONTAMINATION: Sections of the floor are contaminated as the result of a spill of tetrachloroethane- and trichloroethane-containing sludge.

METHOD OF DECONTAMINATION: Tanks were decontaminated by draining the sludges, chipping off the stuck-on material using brass (nonsparking) tools, hand wiping with a stoddard solvent, rinsing, and wet vacuuming. Tanks were then cut up and taken away. Plans for decontaminating the floor have not been finalized; they are expected to be similar to those used on the tanks. Buildings will be destroyed and the whole site capped.

EQUIPMENT: Nonsparking tools, wet vacuum.

WORKER PROTECTION:

EVALUATION OF DECONTAMINATION EFFECTIVENESS: Swipe test.

COSTS:

Appendix A: Superfund Site Survey

REGION: I

DATE: September 23, 1983

SITE: Ottati and Goss/Kingston
Steel Drum

CONTACT: Bob Ankstitus
EPA Region I
617/223-7265

LOCATION: Kingston, New Hampshire

HISTORY OF USE: Both operations reconditioned and resold used 55-gal drums. O&G also operated a hazardous waste TSD facility.

WASTES ON SITE: O&G - 4300 drums; KSD - 40,000 to 60,000 drums. Wastes include flammables, nonflammables, caustics, cyanides, and PCB's.

DESCRIPTION OF BUILDINGS, STRUCTURES, AND EQUIPMENT ON SITE: Emergency response equipment including backhoes, bobcats, and drum grapplers.

CRITERIA FOR DETERMINING CONTAMINATION: Decontamination procedure is routine.

METHOD OF DECONTAMINATION: Equipment was steam cleaned. Water was collected in drums, pumped in with nonflammable wastes, and disposed of.

EQUIPMENT: Steam geny.

WORKER PROTECTION: Level C protection. Operators wore raincoats or rubber aprons.

EVALUATION OF DECONTAMINATION EFFECTIVENESS: No machinery left the site visibly contaminated. Organic vapors were at background levels.

COSTS: The costs are broken down as follows:

Labor: \$30/h
Machinery: \$35 to \$85/h
Steam generator: \$100/day

Appendix A: Superfund Site Survey

REGION: II

DATE: February 14, 1984

SITE: Chemical Control

CONTACT: Fred Schmitt
NJDEP
609/292-1211

LOCATION: Elizabeth, New Jersey

HISTORY OF USE: A plume from an explosion and fire at the site in April 1980 contaminated a cement factory across the street.

WASTES ON SITE: 60,000 drums of assorted chemicals.

DESCRIPTION OF BUILDINGS, STRUCTURES, AND EQUIPMENT ON SITE: Three cement trucks, an office building, and elevator buildings.

CRITERIA FOR DETERMINING CONTAMINATION: Swab samples.

METHOD OF DECONTAMINATION: Washed down with water and solvent.

EQUIPMENT: Spray gun.

WORKER PROTECTION: Level C protection.

EVALUATION OF DECONTAMINATION EFFECTIVENESS: Patch test.

COSTS:

Appendix A: Superfund Site Survey

REGION: II

DATE: March 1, 1984

SITE: Mont Clair/Glen Ridge

CONTACT: John Czapor
EPA Region II
212/264-1574

LOCATION: Essex County, New Jersey

HISTORY OF USE: Soil from the site of a radium processing facility was used as fill material in a residential neighborhood.

WASTES ON SITE: Radium.

DESCRIPTION OF BUILDINGS, STRUCTURES, AND EQUIPMENT ON SITE: Forty homes with basements.

CRITERIA FOR DETERMINING CONTAMINATION: An aerial survey of areas surrounding former radium processing facilities in New Jersey detected elevated levels of gamma radiation in this neighborhood.

METHOD OF DECONTAMINATION: Basements were ventilated until radon gas was reduced to acceptable levels. Removal of the contaminated soil is anticipated.

EQUIPMENT: Helicopters, gamma radiation detectors.

WORKER PROTECTION:

EVALUATION OF DECONTAMINATION EFFECTIVENESS: The acceptable level of radon gas is defined as an annual average (or equivalent) radon decay product concentration (including background) not to exceed 0.02 working level (40 CFR 192.12(b)(1), July 1, 1983, amended by 48 FR 45946, October 7, 1983).

COSTS:

Appendix A: Superfund Site Survey

REGION: II

DATE: February 8, 1984

SITE: Love Canal

CONTACT: Rob Raad
EPA Region II
212/264-0109

LOCATION: Niagara Falls, New York

HISTORY OF USE: Love Canal is a 16-acre below-ground landfill. In the mid-to-late 1970's, continued periods of high precipitation raised the water table, carrying chemically contaminated leachate to the surface and into contact with basement foundations.

WASTES ON SITE: Acids, chlorides, mercaptans, phenols, toluenes, pesticides, chlorobenzenes, benzylchlorides, sulfides and sulphydrates.

DESCRIPTION OF BUILDINGS, STRUCTURES, AND EQUIPMENT ON SITE: About 300 homes are located immediately adjacent to the site, and another 500 homes are located in the surrounding area. The homes in the immediate vicinity were evacuated in 1978 and demolished in 1983. Of the homes in the surrounding area, only 10 percent are still occupied.

CRITERIA FOR DETERMINING CONTAMINATION:

METHOD OF DECONTAMINATION: Currently, the CDC, HHS, and NY State Department of Health are conducting a habitability study to determine what must be done in order for families to be able to move back into their homes. Recommendations are 1-1/2 yr away.

EQUIPMENT:

WORKER PROTECTION:

EVALUATION OF DECONTAMINATION EFFECTIVENESS:

COSTS:

Appendix A: Superfund Site Survey

REGION: III

DATE: September 26, 1983

SITE: Lehigh Electric &
Engineering Co.

CONTACT: Tony Bartolomeo
EPA Region III
215/597-8180

LOCATION: Old Forge, Pennsylvania

HISTORY OF USE: Electrical equipment, including transformers and capacitors, were stored at the site.

WASTES ON SITE: PCB's.

DESCRIPTION OF BUILDINGS, STRUCTURES, AND EQUIPMENT ON SITE: Concrete slabs.

CRITERIA FOR DETERMINING CONTAMINATION:

METHOD OF DECONTAMINATION: Slabs will be scrubbed with a solvent (probably diesel fuel), sealed, and covered with dirt.

EQUIPMENT:

WORKER PROTECTION:

EVALUATION OF DECONTAMINATION EFFECTIVENESS: Wipe sample.

COSTS: The cost of the entire project is an estimated \$5 million.

Appendix A: Superfund Site Survey

REGION: V

DATE: February 8, 1984

SITE: Chem-Dyne

CONTACT: Donald Bruce
EPA Region V
312/886-0399

LOCATION: Hamilton, Ohio

HISTORY OF USE: Chemical waste transfer and storage.

WASTES ON SITE: Pesticide wastes and residues, organic solvents, fire retardants, lab chemicals.

DESCRIPTION OF BUILDINGS, STRUCTURES, AND EQUIPMENT ON SITE: Several buildings are situated on or near the site. The principal building is a combination office/warehouse. The office portion burned in a fire in April 1983. The warehouse portion had been used for equipment and waste storage. It is approximately 100 yd long by 75 ft wide with steel beam construction and brick and wood floorboards. The building is in a dilapidated condition with severe structural damage. Some of the other buildings are in better shape.

CRITERIA FOR DETERMINING CONTAMINATION: CH2M Hill conducted a facilities inventory as part of their remedial investigation. The inventory consisted of photos, visual inspections, and observations. There is considerable evidence of waste spillage, i.e., soaked floorboards, etc.

METHOD OF DECONTAMINATION: A remedial investigation/feasibility study is currently being conducted. The principal building will probably be removed; however, some of the others may be candidates for decontamination. The RI/FS will be available for public distribution in July 1984 and may be obtained from the Miami University library in Oxford, Ohio.

EQUIPMENT:

WORKER PROTECTION:

EVALUATION OF DECONTAMINATION EFFECTIVENESS:

COSTS:

Appendix A: Superfund Site Survey

REGION: VI

DATE: February 14, 1984

SITE: Bio-Ecology Systems, Inc.

CONTACT: Steve Romanow
EPA Region VI
214/767-9716

LOCATION: Grand Prairie, Texas

HISTORY OF USE: Permitted for incineration, chemical treatment, biological oxidation of wastewaters, and landfill of solids resulting from treatment processes.

WASTES ON SITE: Heavy metal sludges, chlorinated organics, volatile organics, PCB's.

DESCRIPTION OF BUILDINGS, STRUCTURES, AND EQUIPMENT ON SITE: Sixteen tanks ranging from 5000 to 20,000 gal and a sheet metal shack.

CRITERIA FOR DETERMINING CONTAMINATION: Tanks contained hazardous materials.

METHOD OF DECONTAMINATION: Tanks were emptied, cleaned with a heavy strength industrial cleaner, double rinsed, and steam cleaned. Water was collected and taken to a secure landfill. Tanks and the shack were cut up with a torch and removed.

EQUIPMENT: High-pressure hose, organic vapor analyzer.

WORKER PROTECTION: Level B. To the extent possible, nobody entered the tanks.

EVALUATION OF DECONTAMINATION EFFECTIVENESS: Tanks were checked with an OVA until readings were at background levels.

COSTS: Bid at \$99,868 (includes safety requirements).

Appendix A: Superfund Site Survey

REGION: VII

DATE: January 1984

SITE: Quail Run Mobile Manor

CONTACT: Bill Keffer
EPA Region VII
913/236-3880

LOCATION: Gray Summit, Missouri

HISTORY OF USE: Waste oil was sprayed on the roads in this mobile home park to control dust.

WASTES ON SITE: Dioxin-contaminated soil.

DESCRIPTION OF BUILDINGS, STRUCTURES, AND EQUIPMENT ON SITE: Mobile homes.

CRITERIA FOR DETERMINING CONTAMINATION: Dioxin-contaminated dust found in household vacuum cleaner bags.

METHOD OF DECONTAMINATION: Vacuuming using HEPA filters, damp wiping, and cleaning of crevices with a soft bristle paint brush.

EQUIPMENT: HEPA filter-equipped vacuums, soft bristle paint brushes.

WORKER PROTECTION: Level C protection.

EVALUATION OF DECONTAMINATION EFFECTIVENESS: Stringent visual evaluation.

COSTS: \$870/residence

Appendix A: Superfund Site Survey

REGION: VIII

DATE: February 14, 1984

SITE: Anaconda Smelter

CONTACT: Bruce Schmitt
Cleveland Wrecking
406/563-3464

LOCATION: Anaconda, Montana

HISTORY OF USE: Copper smelter.

WASTES ON SITE: Flue dust contaminated with arsenic (up to 30 percent), lead, and cadmium (considered a mining waste).

DESCRIPTION OF BUILDINGS, STRUCTURES, AND EQUIPMENT ON SITE: Over 100 buildings are on site, some of which are very old. Hydrometallurgical processes concentrated the raw ore while pyrometallurgical processes burned off the impurities. Flue dust collected in the flue system associated with the ovens.

CRITERIA FOR DETERMINING CONTAMINATION: The ESP unit is full of contaminated flue dust (50 ft deep), as is the flue system (2400 ft long, 20 ft deep). Process dust is in all of the buildings.

METHOD OF DECONTAMINATION: The buildings are being torn down. The dust is handled as it is encountered. A front-end loader picks up the dust and deposits it in a dump truck to be taken to a secure landfill. Water is sprayed continuously to keep fugitive emissions down.

EQUIPMENT: Front-end loaders, dump trucks, hoses.

WORKER PROTECTION: Workers wear respirators (air-powered, full face, or half mask) and cloth suits with gauze to tie off the sleeves and pant legs. (The suits are laundered every night.) "Dirty" rooms are separated from "clean" rooms, and workers must take showers before leaving for the day.

EVALUATION OF DECONTAMINATION EFFECTIVENESS:

COSTS: The cost of the whole project is an estimated \$9 million; \$1 million of which is allocated for the removal of contaminated flue dust and other environmental and human health hazards.

Appendix A: Superfund Site Survey

REGION: IX

DATE: September 28, 1983

SITE: Taputimu Farm

CONTACT: Marvin Young
EPA Region IX
415/974-8142

LOCATION: American Samoa

HISTORY OF USE: Part of an agricultural experimental farm used to store unused chemicals and pesticides.

WASTES ON SITE: Pesticides.

DESCRIPTION OF BUILDINGS, STRUCTURES, AND EQUIPMENT ON SITE: Three rooms of a warehouse and a trailer are suspected of being contaminated. Once the buildings have been decontaminated, they will be used to store equipment.

CRITERIA FOR DETERMINING CONTAMINATION: The warehouse floods regularly, and some hazardous materials have reportedly been washed out of the facility.

METHOD OF DECONTAMINATION: Currently a record of decision is being developed. Remedial action which has been recommended includes total removal of all materials (pack or overpack, ship to mainland to an approved disposal site); sweeping, vacuuming, and wiping down of all buildings; and sealing decontaminated surfaces.

EQUIPMENT:

WORKER PROTECTION:

EVALUATION OF DECONTAMINATION EFFECTIVENESS: Surface sampling.

COSTS: Projected \$160,000. Razing the site was not considered.

Appendix A: Superfund Site Survey

REGION: IX

DATE: October 31, 1983

SITE: MGM Brakes

CONTACT: David Sykes
IT Corp.
415/228-8400

LOCATION: Cloverdale, California

HISTORY OF USE: Between 1965 and 1972, this facility operated casting machines that used hydraulic fluids containing PCB's. These fluids were discharged to the ground on site.

WASTES ON SITE: Waste oil containing PCB's.

DESCRIPTION OF BUILDINGS, STRUCTURES, AND EQUIPMENT ON SITE: Aluminum butler buildings with concrete slab floors (40,000 ft²), aluminum casting machinery and other metal handling equipment, and concrete drainage grates.

CRITERIA FOR DETERMINING CONTAMINATION: The State determined that the entire facility is contaminated.

METHOD OF DECONTAMINATION: High-pressure water, detergent, and solvent on floors, walls, ceilings, roofs, and equipment.

EQUIPMENT: 10,000 psi water blaster.

WORKER PROTECTION: Tie-back clothing, rainsuits, boots, gloves, respirators, and continuous workplace monitoring. A perimeter was established around the contaminated area.

EVALUATION OF DECONTAMINATION EFFECTIVENESS: Surfaces that tested <70 µg PCB/100 cm² were considered clean.

COSTS: \$300,000. It would have cost several million dollars to raze and rebuild the site.

APPENDIX B

SAMPLING METHODS

This appendix presents two basic surface sampling techniques (wet-wipe and dry-wipe sampling), as well as techniques for measuring asbestos fibers in air and heavy metal and explosives contamination in sumps.

In surface-wipe sampling, a surface is wiped with a cotton swab or filter paper that may or may not be wetted with a solvent. The sample is then submitted to a laboratory for analysis of appropriate chemical contaminants. This approach usually provides fairly reliable information on the presence of contaminants, but it often suffers from two major deficiencies. First, the collection efficiency of this sampling procedure is unknown and highly variable; therefore, maximum analytical sensitivity must be used when analyzing these samples. Secondly, sample turnaround time may be quite long. Surface wipe sampling will confirm that a target concentration has been reached or that additional cleanup is necessary, but it will not give a quick or real-time check on decontamination efforts. In these instances, chemical spot tests or direct reading instrumental evaluations may be preferable to wipe tests (personal communication from C. L. Geraci, Jr., Division of Physical Sciences and Engineering, National Institute for Occupational Safety and Health, Cincinnati, Ohio, August 30, 1984). These tests are described in References 1, 2, 3, and 4 at the end of this appendix.

WET-WIPE TEST (VERSION A)

Building surfaces and vents at Frankford Arsenal were tested with acetone-saturated cotton swabs to determine explosives contamination.⁵

Materials

The following materials are needed in this test:

- Q-tip, wooden stem
- Acetone, "distilled-in-glass" Nanograde
- 2 dram vial with Teflon-lined cap
- Amber glass bottle, 1 pint
- Plastic Nalgene bottle, 1 quart

Appendix B: Sampling Methods

Procedure

Swab test procedures are as follows:

- ° Mark off five 5-cm-diameter circles distributed at the four corners and center of a 1-m² area for building surfaces or one 5-cm-diameter circle for vents and other surfaces.
- ° Dip a wooden stem Q-tip in a 2-dram vial containing 1.5 ml of acetone. Swab one circle at a time, dipping the Q-tip in the acetone before and after each circle is swabbed.
- ° When all circles have been swabbed, tightly seal the acetone-containing vial with a Teflon-lined cap and discard the used swab.
- ° Preserve the collected sample at 4°C.
- ° Prior to analysis, allow the sample to warm to ambient temperature.
- ° To compensate for possible solvent evaporation during transport, adjust the final volume of the sample with acetone to 1.5 ml.
- ° Analyze the sample for explosive compounds by directly injecting 20 μ l of the acetone extract into a high-pressure liquid chromatograph.
- ° When resampling an area following surface decontamination, position the sampling grid 15 cm to the right of the initial sampling points or, if movement to the right is restricted, 15 cm downward.

WET-WIPE TEST (VERSION B)

Cotton swabs soaked in an acetone/hexane mixture were used to sample for dioxin on smooth, solid, nonabsorbing surfaces (e.g., ceramic tiles, polished marble, and glass panes) in Seveso, Italy.⁶

Materials

The following materials are needed in this test:

- Cotton swab, degreased
- Acetone, pesticide grade
- Hexane, pesticide grade
- Isooctane, pesticide grade
- Metal clamp
- Glass-stoppered glass jar
- 10-ml cone-shaped-bottom vial with glass stopper or Teflon-lined screw cap

Procedure

Wet wipe procedures are as follows:

- Mark off a square area of approximately 0.25 m² on the surface to be wiped.
- While holding in a clean metal clamp, saturate a 10-g degreased cotton swab with 20 to 30 ml of a 1:4 acetone/hexane mixture.
- While still holding the cotton swab in the clamp, wipe the sampling area back and forth repeatedly in a vertical direction, applying moderate pressure.
- Turn the swab over and wipe back and forth in the horizontal direction.
- Store the used swab in a glass-stoppered glass jar until extraction can be performed.
- Extract the used swab with three fractions (200 ml each) of the 1:4 acetone/hexane mixture.
- Pool the three fractions and dry under vacuum.
- Clean the extraction residue by column chromatographic techniques.
- Store the dried sample from the final cleanup step in a 10-ml cone-shaped-bottom vial sealed with either a glass stopper or a Teflon-lined screw cap.
- Analyze the sample for TCDD by dissolving the residue in a known volume of isooctane and injecting an aliquot into a low-resolution gas-liquid chromatograph in combination with an MID/mass spectrometer. A detection threshold in the range of 1 to 20 ng/m² for this analysis scheme has been reported in the literature.

DRY-WIPE TEST

Building and vent surfaces suspected of radiological contamination at Frankford Arsenal were sampled by a dry-wipe technique.⁷

Materials

A 2.4-cm-diameter filter paper disk is required for this test.

Appendix B: Sampling Methods

Procedure

Dry wipe test procedures are as follows:

- ° Wipe a 2.4-cm-diameter filter paper disk in a Z or S pattern over a representative portion of the surface to be sampled, using the tip of the thumb. The length of the wipe should be 50 cm. (Since the pressure-bearing portion of the filter paper disk will be about 2 cm wide, the area of the surface sampled will be approximately 100 cm².)
- ° Avoid contacting excess dirt when wiping an area.
- ° Test the sample with appropriate instruments for determining radiological contamination.

ASBESTOS FIBERS IN AIR

The NIOSH method for measuring asbestos fibers in air (Method No. P & CAM 239, 1977) is the method currently used by OSHA for assessing occupational exposures to airborne fiber concentrations.⁸

Materials

The following materials are needed for sample collection:

- Battery-powered personal sampling pump capable of sampling at a flow rate of 1.0 to 2.5 liters per min.
- Rubber or plastic tubing
- Clothing spring clip
- Tubing-to-field monitor adaptor
- Field monitor (filter and holder) - manufactured by Millipore Corporation; a three-section styrene plastic case, 37-mm diameter plain white cellulose ester membrane with 0.8 μ m pore size, support pad, and two plastic sealing caps

Procedure

The principle of the sampling method is to draw air through a membrane filter by means of a personal sampling pump. Asbestos fibers, collected on the membrane filter, are sized and counted using phase-contrast microscopy. Sample collection procedures are as follows:

- ° Calibrate personal sampling pumps in the laboratory before field-use to a flow rate of 1.0 to 2.5 liters per min.
- ° Attach the sampling pump to a worker's belt (for a personal exposure measurement) or to a stationary location (for an area measurement).

- Remove the top cover of the field monitor. Invert the monitor so that the exposed filter is facing downward.
- Turn on the sampling pump.
- Record the following information: filter number, pump start time and date, flow rate, subject's name and job title (personal sample) or location (area sample), and type of operation or process.
- Periodically check the sampling equipment for proper operation and flow rate.
- Optimum sampling time is generally 6 to 8 h.
- At the end of the sampling time, turn off the pump and recap the field monitor.
- Analyze the sample by phase-contrast microscopy. For sample volumes of approximately 1000 liters of air, the lower detection limit is about 0.03 fibers per cm^3 of air. This method does not distinguish asbestos fibers from nonasbestos fibers.

SUMP SAMPLING

The degree and character of sump contamination at the Frankford Arsenal were assessed by collecting and analyzing sump samples for heavy metals and explosives.⁵

Materials

The following materials are required for sump sampling:

Wastewater vacuum pump sampler
Tygon tubing, 1 cm i.d.
Amber glass bottle, 500 ml
Polyethylene bottle, 1 liter
Rubber stopper

Procedure

Procedures for sump sampling are as follows:

- Attach a clean piece of Tygon tubing (about 0.3 to 0.5 m) to the silicone rubber tubing outlet of the sampler (see Figure B-1).
- Connect the other end of the Tygon tubing to the inlet tube in the stopper of the sample container (polyethylene bottle for heavy metal contamination, glass bottle for explosives contamination).

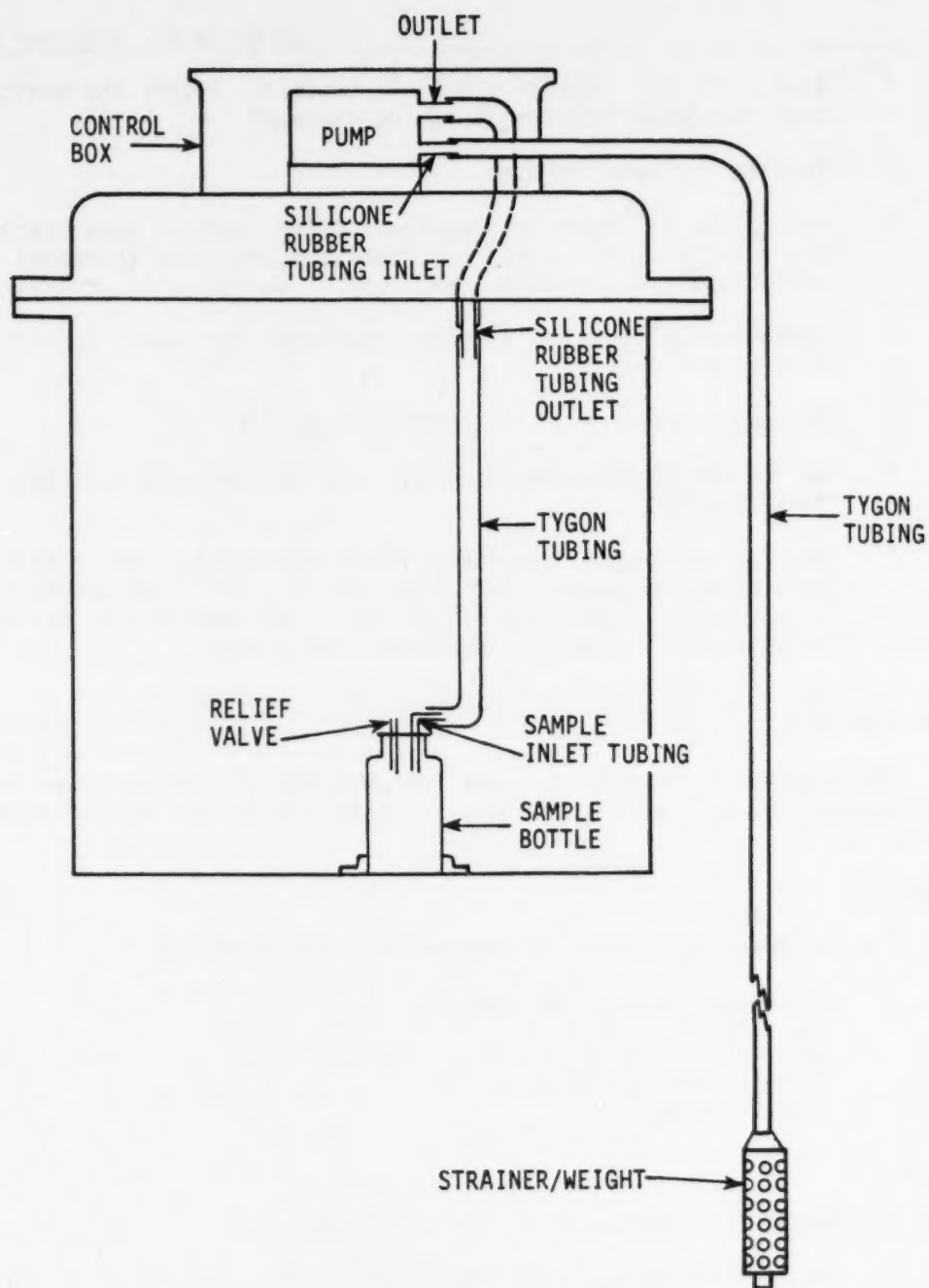


Figure B-1. Sump sampling configuration.

- ° Place the sample container at the bottom of the sampler and secure it with tape or padding.
- ° Close the sampler lid.
- ° Attach a second piece of Tygon tubing of sufficient length to reach the bottom of the sump to the silicone rubber tubing inlet of the sampler.
- ° Connect the strainer/weight to the other end of the Tygon tubing.
- ° Lower the strainer/weight-bearing end of the tubing into the sump.
- ° Set the volume selector control to the desired volume corresponding to the head height, and turn the pump switch to "auto."
- ° When the sample has been collected, open the sampler, remove the bottle, and replace it with an empty bottle.
- ° Remove the tubing assembly from the well.
- ° Flush out the sampler by running a large volume of distilled water through it.
- ° Clean the strainer/weight with lab glassware detergent and rinse with distilled water.
- ° Replace the Tygon tubing between sampling of wells to avoid cross-contamination of sump samples.
- ° Preserve the sample at 4°C. Prior to analysis, allow the sample to warm to ambient temperature.
- ° Filter the sample through a Whatman 2 filter to remove suspended insoluble material.
- ° Analyze the filtrate and residue for explosives by high-pressure liquid chromatography.

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APPENDIX C

COST ANALYSIS

This appendix presents an order-of-magnitude cost analysis for several of the well-established decontamination methods described in Section 4. For comparison of the costs of the different methods, a model building having the following characteristics* was assumed:

- ° The building has two stories and is 60 ft long, 30 ft wide, and 25 ft high (inside dimensions).
- ° Each of the two stories has 1800 ft² of floor area and 1800 ft² of ceiling area, and the building's total wall area is 4500 ft².
- ° The floor slabs and walls are constructed of concrete; the ceilings are covered with asbestos panels.
- ° The walls and foundation are 1 ft thick; the floor of the second story is 4 in. thick.
- ° The building contains 5 tons of steel, including 1 boiler, 60 ft of piping, and stairs.

COST ESTIMATE BASES

Capital Costs

Costs for methods 5, 8, 13, 15, 16, and 18 were based on the assumption that the needed equipment would have to be purchased. (For all other methods, equipment rental was assumed.) Capital equipment costs are based on Peters and Timmerhaus,¹ Means 1982,² Means 1984,³ Decommissioning Handbook,⁴ The Chemical Marketing Reporter,⁵ and in-house estimates.

Equipment Rental Costs

Costs for rental of equipment are based on Means^{2,3} or represent quotes from vendors.

* Unit costs in the literature are expressed in U.S. customary units. For this reason, the dimensions of the building are also expressed in U.S. customary units, and metric conversion factors are presented at the end of this appendix (Table C-17).

Appendix C: Cost Analysis

Operating Costs

The operating cost components include labor, administration and overhead, and materials/other.

Labor--

The labor rate is estimated to be \$12/h. Labor encompasses setup, operation, tear-down, waste disposal, and refinishing the building. The following assumptions were made for estimating labor times:

- ° Equipment tear-down time equals 75 percent of setup time.
- ° Normal cleanup requires 80 h per building and includes repainting.

Administration and Overhead--

Administration and overhead costs are assumed to be four times those of labor costs. These costs include purchasing, safety analysis, verification of decontamination, and normal amounts of utilities (steam, electricity, water, sanitary sewage). Waste disposal costs are assumed to be part of overhead unless the waste generated is hazardous and requires incineration or disposal in a secure landfill.

Other Operating Costs--

Material costs are assumed to be the delivered price of the material. Material cost estimates are based on costs in The Chemical Marketing Reporter⁵ or a specialty chemical catalog.

The cost of Level C protective gear (consisting of coveralls, boots, gloves, respirator, and hard hat) is assumed to be \$1000. If special protective gear (e.g., fully encapsulating suit, self-contained breathing apparatus) is required, the cost would be considerably higher.

It is assumed that hazardous wastes generated as a result of decontamination operations and requiring incineration or disposal in a secure landfill will be handled at \$12/ft³.

Costs for sampling and analysis of contaminants and long-term monitoring of residuals are not included in this cost analysis.

RELATIVE COST PERSPECTIVE

The costs presented in this section are preliminary cost estimates with a best accuracy of ± 50 percent. Site-specific factors, particularly the nature of the contaminants present, will influence the actual decontamination costs. A summary of the cost estimates developed in this appendix is presented in Table C-1.

TABLE C-1. SUMMARY OF ESTIMATED COSTS FOR SELECTED DECONTAMINATION METHODS

Decontamination method	Building applicability	Estimated cost, ^a \$
Building replacement	Entire building (3600 ft ²)	120,000
Asbestos removal	Ceilings (3600 ft ²), pipe (60 ft)	24,540
Asbestos encapsulation	Ceilings (3600 ft ²)	2,160
Absorption	One floor (1800 ft ²)	3,760
Demolition	Entire building (3600 ft ²)	66,070
Dismantling	Boiler, stairs, pipe (60 ft)	5,038
Dusting/vacuuming/wiping	Floors (3600 ft ²)	3,560
Gritblasting	Walls, floors (8100 ft ²)	53,863
Hydroblasting	Walls, floors (8100 ft ²)	137,004
Painting/coating	Walls (4500 ft ²)	3,365
Scarification	Walls, floors (8100 ft ²)	59,455
Steam cleaning	Walls, floors (8100 ft ²)	22,760
Acid etching	Walls, floors (8100 ft ²)	10,087
Bleaching	Walls, floors (8100 ft ²)	16,162
Flaming	Walls, floors (8100 ft ²)	3,132
Drilling and spalling	Walls, one floor (6300 ft ²)	109,922

^a Includes labor, equipment, materials, waste disposal, overhead, and profit.

Appendix C: Cost Analysis

The summary in Table C-1 permits a comparison of the order-of-magnitude costs of each of the decontamination methods and serves as a perspective for analysis of decontamination versus removal and replacement. Removal and replacement of the contaminated building and associated equipment would require the following:

Removal of asbestos from ceilings and pipe	\$ 24,540
Dismantling of boiler, stairs, and pipe	5,038
Demolition of building (including disposal of debris)	66,070
Subtotal	\$ 95,648
Construction of replacement building	120,000
Total	\$215,648

Decontamination of buildings, structures, and equipment at Superfund sites should be considered only when such action is cost-effective; i.e., when the costs of decontamination are less than those of removal and disposal of the contaminated structure and construction of a replacement building.

INDIVIDUAL COST ANALYSES

Asbestos Removal (Method 1A)

Costing of this technique is based on the assumption that asbestos was present in the building as asbestos panels covering the ceilings and asbestos insulation along the pipes. Therefore, the total area of ceiling paneling to be removed would be 3600 ft², and the total length of insulation to be removed from pipes would be 60 ft.

Price quotes obtained from an asbestos-removal company included labor, labor protection, asbestos disposal, equipment, overhead, and profit.⁶

The removed asbestos insulation would have to be replaced with another type of insulation. A typical fiberglass insulation was chosen and costed with prices taken from Means.³ These costs include labor, equipment, materials, overhead, and profit.

A summary of the costs is given in Table C-2.

Asbestos Encapsulation (Method 1B)

The model building was assumed to have asbestos panels covering the ceiling and asbestos insulation along the pipes; therefore, 3600 ft² of ceiling and 60 ft of pipe would require treatment.

The method of encapsulation was assumed to be by sprayed sealant. Labor costs for this technique and labor output rates were found in Means.³ A rate of 6666 ft²/day was given for ceiling encapsulation, and a rate of 1538 ft/day was given for pipe encapsulation. Therefore, less than a day should be required for treatment of the model building.

TABLE C-2. ASBESTOS REMOVAL COST ANALYSIS
(1984 dollars)

Item	Cost, \$
<u>Operating costs</u>	
Removal of ceiling insulation ^{a,b} \$6.00/ft ² x 3600 ft ² =	21,600
Removal of pipe insulation ^{a,b} \$9.00/ft x 60 ft =	540
Replacement of ceiling insulation ^{c,d} \$0.45/ft ² x 3600 ft ² =	1,620
Replacement of pipe insulation ^{c,d} \$13.00/ft x 60 ft =	780
Protective gear ^e	0
TOTAL OPERATING COSTS	24,540

^a Includes labor, labor protection, asbestos cleanup and disposal, equipment, overhead, and profit.

^b Reference 6.

^c Includes labor, materials, overhead, and profit.

^d Reference 2.

^e Cost of personnel protection is included in the decontamination costs (i.e., removal). No personal protective gear is expected to be necessary during insulation replacement.

Appendix C: Cost Analysis

Each gallon of sealant was estimated to cover 200 ft² of ceiling or 100 ft of pipe. Therefore, the number of gallons of sealant required to complete the job would be:

$$\frac{3600 \text{ ft}^2}{200 \text{ ft}^2/\text{gal}} + \frac{60 \text{ ft}}{100 \text{ ft}/\text{gal}} = 19 \text{ gal}$$

A summary of the costs is given in Table C-3.

Absorption (Method 2)

Absorbents are only suitable for spills on metal and well-sealed wood surfaces; concrete tends to absorb the spill before it can be retrieved. Therefore, for the purpose of this cost analysis, the first story of the building is assumed to have a wood floor on which 100 gal of hazardous liquid has been spilled.

Assuming the use of diatomaceous earth at 20 lb/gal of liquid spilled, a total of 2000 lb of absorbent would be needed.

Costing of the disposal of the contaminated absorbent was based on an estimate that each 50-lb bag would assume a volume of 2 ft³ when wet. Therefore, the volume of hazardous debris requiring landfill would be:

$$2000 \text{ lb absorbent} \times 2 \text{ ft}^3/50 \text{ lb} = 80 \text{ ft}^3$$

A summary of costs is given in Table C-4.

Demolition (Method 3)

The cost for demolition of the model concrete building was calculated with a cost figure given in Means.³ This figure was given in terms of the volume of the building based on external dimensions. For the model building, these dimensions are 62 ft long x 32 ft wide x 27 ft high. Thus, the volume of the building would be:

$$62 \text{ ft} \times 32 \text{ ft} \times 27 \text{ ft} = 53,568 \text{ ft}^3$$

It was assumed that the debris generated would have to be disposed of in a hazardous waste landfill. Because of the large amount of debris involved, a cost for bulk hazardous disposal was derived from a combination of in-house estimates and a vendor's quote.

A summary of costs is given in Table C-5.

Dismantling (Method 4)

This cost analysis is restricted to the 5 tons of steel equipment (boiler, stairs, 60 ft of pipe) included in the model building. It was assumed

TABLE C-3. ASBESTOS ENCAPSULATION COST ANALYSIS
(1984 dollars)

Item	Cost, \$
<u>Operating costs</u>	
Labor	
Encapsulation of ceiling panels ^{a,b}	
\$0.14/ft ² x 3600 ft ² =	\$ 504
Encapsulation of pipes ^{a,b}	
\$0.59/ft x 60 ft =	<u>36</u>
	540
Other operating costs	
Encapsulant ^c	
\$31/gal x 19 gal =	\$ 589
Sprayer rental ^c	
\$31/day x 1 day =	31
Level C protective gear	<u>1,000</u>
	<u>1,620</u>
TOTAL OPERATING COSTS	2,160

^a Includes setup, tear-down, overhead, and profit.

^b Reference 3.

^c Reference 2.

TABLE C-4. ABSORPTION COST ANALYSIS
(1984 dollars)

Item	Cost, \$
<u>Operating costs</u>	
Labor	
Application of absorbent ^a	
6 h/building	6 h
Cleanup ^a	
20 h/building	<u>20 h</u>
	26 h
At \$12/h, labor = 26 h x \$12/h =	312
Overhead	
At 4 x labor cost = 4 x \$312 =	1,248
Other operating costs	
Absorbent ^b	
\$6/50-lb bag x 40 bags =	\$ 240
Landfilling of debris ^a	
\$12/ft ³ x 80 ft ³ =	960
Level C protective gear	<u>1,000</u>
	<u>2,200</u>
TOTAL OPERATING COSTS	3,760

^a Estimate.

^b Vendor quote.

TABLE C-5. DEMOLITION COST ANALYSIS
(1984 dollars)

Item	Cost, \$
<u>Operating costs</u>	
Demolition and cleanup of building ^{a,b}	
$\$0.21/\text{ft}^3 \times 53,568 \text{ ft}^3 =$	11,250
Landfilling of debris (in bulk) ^c	
$\$7.80/\text{ft}^3 \times 6900 \text{ ft}^3 =$	53,820
Level C protective gear	<u>1,000</u>
TOTAL OPERATING COSTS	66,070

- ^a Includes labor, equipment, materials, overhead, and profit.
^b Reference 2.
^c Estimate.

Appendix C: Cost Analysis

that none of the equipment was salvageable and that all of it must be disposed of in a hazardous landfill. A quote on a bulk rate for hazardous disposal was obtained from a vendor.

Costs for pipe and stair dismantlement (including labor, equipment, materials, overhead, and profit) were taken from Means.³

A summary of costs is given in Table C-6.

Dusting/Vacuuming/Wiping (Method 5)

Almost all the cost for this decontamination method is for labor. The only capital cost would be for some small commercial vacuums.

For this cost analysis, it was assumed that both floors of the building were contaminated with hazardous dust, and that a single treatment would satisfactorily clean the building surfaces.

A summary of costs is given in Table C-7.

Gritblasting (Method 7)

Gritblasting would be used to remove the contaminated surface of both concrete walls and floors; therefore, the total area to be treated in the model would be 8100 ft².

Means³ gave a cost for gritblasting that included labor, equipment, materials, overhead, and profit.

The daily amount of surface treated by a typical machine (for 1/8-in. surface removal) is 375 ft², which would entail the use 6 tons (133.3 ft³) of grit. Thus, the number of days required for the surface removal would be:

$$\frac{8100 \text{ ft}^2}{375 \text{ ft}^2/\text{day}} = 21.6 \text{ days}$$

The amount of debris generated by this process would include the concrete removed:

$$8100 \text{ ft}^2 \times 1/8 \text{ in.} \times 1 \text{ ft}/12 \text{ in.} \approx 85 \text{ ft}^3$$

and the grit used by the machine:

$$133.3 \text{ ft}^3/\text{day} \times 21.6 \text{ days} \approx 2880 \text{ ft}^3$$

The volume of concrete removed from walls and floors was multiplied by a factor of 1.5 to account for expansion (the density of solid concrete is

TABLE C-6. DISMANTLING COST ANALYSIS
(1984 dollars)

Item	Cost, \$
<u>Operating costs</u>	
Labor	
Dismantling of boiler ^a	
25 h/boiler	25 h
Cleanup of building ^a	
30 h/building	30 h
	55 h
At \$12/h, labor cost = 55 h x \$12/h	660
Overhead	
At 4 x labor cost = 4 x \$660 =	2,640
Other operating costs	
Dismantling of pipe ^b	
\$2.30/ft x 60 ft =	\$ 138
Dismantling of stairs ^b	
\$15/riser x 20 risers =	300
Landfilling of debris ^c	
\$60/ton x 5 tons =	300
Level C protective gear	<u>1,000</u>
	<u>1,738</u>
TOTAL OPERATING COSTS	5,038

^a Estimate.

^b Includes labor, equipment, materials, overhead, and profit.

^c Vendor quote.

TABLE C-7. DUSTING/VACUUMING/WIPING COST ANALYSIS
(1984 dollars)

Item	Cost, \$
<u>Operating costs</u>	
Labor	
Vacuuming/dusting/wiping of floors ^a	
40 h/building 40 h	
At \$12/h, labor = 40 h x \$12/h =	480
Overhead	
At 4 x labor cost = 4 x \$480 =	1,920
Other operating costs	
Level C protective gear	<u>1,000</u>
TOTAL OPERATING COSTS	3,400
<u>Capital costs</u>	
Small hand-held vacuum (Dustbuster) ^b	
4 @ \$40 = \$ 160	
TOTAL CAPITAL COSTS	<u>160</u>
TOTAL COST OF DUSTING/VACUUMING/WIPING	3,560

^a Estimate.

^b Vendor quote.

greater than that of concrete chips and dust). Thus, the total volume of hazardous debris to be disposed of is:

$$85 \text{ ft}^3 \times (1.5) + 2880 \text{ ft}^3 \approx 3008 \text{ ft}^3$$

A summary of costs is presented in Table C-8.

Hydroblasting (Method 8)

The cost of a basic hydroblaster unit with a rate of 11 gal/min at 10,000 lb/in.² was quoted by a manufacturer at \$27,100 plus \$6850 for accessories that allow cleaning the inside of tanks, pipes, and sumps.

The Decommissioning Handbook⁴ cites that a removal depth of 0.74 in. at a rate of 10 ft²/h is typical. The time required to decontaminate the model building (8100 ft² of concrete surface) when two shifts are used is:

$$\frac{8100 \text{ ft}^2}{10 \text{ ft}^2/\text{h}} \times \frac{1 \text{ day}}{16 \text{ h}} \approx 51 \text{ days}$$

A pump will be required for continuous removal of water from the sumps. A maximum hydroblasting rate of 11 gal/min requires a pump capable of 11 gal/min plus about 20 ft of head. The cost of the pump is \$870.¹

If the water is to be recycled, storage tanks are required. At a rate of 11 gal/min, a tank holding one day's supply must have a capacity of:

$$11 \text{ gal/min} \times 60 \text{ min/h} \times 16 \text{ h/day} \times 1 \text{ day} \approx 11,000 \text{ gal}$$

The cost of a mild-steel 11,000-gal tank is estimated to be \$16,350. The need for two tanks is assumed, one for recycle water to be fed to the hydroblaster and one for storage. If the hydroblaster removes 0.75 in. of surface from the walls and floors, then the amount of debris to be disposed of would be:

$$8100 \text{ ft}^2 \times 0.75 \text{ in.} \times 1 \text{ ft}/12 \text{ in.} \approx 507 \text{ ft}^3$$

A summary of the costs is given in Table C-9.

Painting/Coating (Method 9A)

For costing purposes, it was assumed that the walls would be the only area coated; therefore, the total area to be painted would be 4500 ft².

It was also assumed that 3 coats (1 coat primer, 2 coats semigloss) of paint would be applied with a sprayer. If another type of coating was desired, the number of coats and cost of materials would probably be different.

TABLE C-8. GRITBLASTING COST ANALYSIS
(1984 dollars)

Item	Cost, \$
<u>Operating costs</u>	
Gritblasting of walls and floors ^{a,b}	
$\$2.07/\text{ft}^2 \times 8100 \text{ ft}^2 =$	16,767
Landfilling of debris ^c	
$\$12/\text{ft}^3 \times 3008 \text{ ft}^3 =$	36,096
Level C protective gear	<u>1,000</u>
TOTAL OPERATING COSTS	53,863

^a Includes labor, equipment, materials, overhead, and profit.

^b Reference 3.

^c Estimate.

TABLE C-9. HYDROBLASTING COST ANALYSIS
(1984 dollars)

Item	Cost, \$
<u>Operating costs</u>	
Labor	
Setup of tanks/pump ^a	
80 h/building	80 h
Setup of equipment ^a	
1 h/day x 30 days	30 h
Hydroblasting of building ^b	
1 h/10 ft ² x 8100 ft ²	810 h
Hydroblasting of equipment ^a	
80 h/building	80 h
Cleanup (painting) ^a	
40 h/building	40 h
	1040 h
At \$12/h, labor cost = 1040 h x \$12/h =	12,480
Overhead	
At 4 x labor cost = 4 x \$12,480 =	49,920
Other operating costs	
Landfilling of debris ^a	
\$12/ft ³ x 507 ft ³ =	\$ 6,084
Level C protective gear	1,000
	7,084
TOTAL OPERATING COSTS	69,484
<u>Capital costs</u>	
Hydroblaster (10,000-lb/in. ²) ^c	\$27,100
Pipe- and tank-cleaning accessories ^c	6,850
Sump pump (11-gal/min) ^d	870
Storage tanks (11,000-gal) ^d	
2 @ \$16,350 =	32,700
TOTAL CAPITAL COSTS	67,520
TOTAL COST OF HYDROBLASTING	137,004

^a Estimate.

^b Reference 4.

^c Vendor quote.

^d Reference 1.

Appendix C: Cost Analysis

The number of man-hours required to cover 4500 ft² with 3 coats of paint was calculated using an output rate given by Means:³

$$4500 \text{ ft}^2 \times 0.2 \text{ h/100 ft}^2/\text{coat} \times 3 \text{ coats} = 27 \text{ h or } \sim 4 \text{ days}$$

The amount of paint required for the task was calculated with a coverage rate given by Means:³

$$4500 \text{ ft}^2 \times 1 \text{ gal/550 ft}^2 = 8.2 \text{ gal or } \approx 9 \text{ gal per coat}$$

A summary of these costs is given in Table C-10.

Scarification (Method 10)

Scarification would be used to remove the contaminated surface of both concrete walls and floors; therefore, the total area to be treated in the model would be 8100 ft².

Costs for scarification, which include operating cost, air consumption, dust and chip removal, and subcontractors' overhead and profit, were taken from the Decommissioning Handbook.⁴ These costs were updated from 1980 dollars to 1984 dollars by use of Chemical Engineering Cost Indices (June 11, 1984).

The removal rate of a typical seven-piston floor scarifier is 315 ft²/h. The removal rate for a typical three-piston wall scarifier is 72 to 108 ft²/h. These rates represent a removal depth of 1 in. The number of man-hours (one operator) required to complete scarification would then be:

$$\frac{3600 \text{ ft}^2}{315 \text{ ft}^2/\text{h}} + \frac{4500 \text{ ft}^2}{72 \text{ ft}^2/\text{h}} = 74 \text{ h}$$

The volume of concrete removed from walls and floors was multiplied by a factor of 2 to account for expansion (the density of solid concrete is greater than that of concrete chips and dust).

The approximate volume of hazardous debris to be disposed of is then:

$$8100 \text{ ft}^2 \times 1 \text{ in.} \times 1 \text{ ft/12 in.} \times (2) = 1350 \text{ ft}^3$$

Because the scarifier leaves behind a rough and uneven surface, additional cost would be incurred to patch the floors and walls.

A summary of the costs is given in Table C-11.

Steam Cleaning (Method 13)

Steam cleaning would be used to clean the concrete walls and floors of the model building; therefore, the total area to be treated would be 8100 ft².

TABLE C-10. PAINTING/COATING COST ANALYSIS
(1984 dollars)

Item	Cost, \$
<u>Operating costs</u>	
Labor	
Setup and tear-down of equipment ^a	
1 h/day x 4 days = 4 h	
Painting of walls ^b	
27 h/building 27 h	
31 h	
At \$12/h, labor cost = 31 h x \$12/h =	372
Overhead	
At 4 x labor cost = 4 x \$372 =	1,488
Other operating costs	
Sprayer rental ^b	
\$31/day x 4 days = \$ 124	
Paint (primer) ^b	
\$14/gal x 9 gal = 126	
Paint (semigloss) ^b	
\$15/gal x 17 gal = 255	
Level C protective gear 1,000	
	<u>1,505</u>
TOTAL OPERATING COSTS	3,365

^a Estimate.

^b Reference 3.

TABLE C-11. SCARIFICATION COST ANALYSIS
(1984 dollars)

Item	Cost, \$
<u>Operating costs</u>	
Scarification and cleanup of walls ^{a,b} \$0.92/ft ² x 4500 ft ² =	4,140
Scarification and cleanup of floors ^{a,b} \$0.21/ft ² x 3600 ft ² =	756
Patching of walls ^{a,c} \$4.35/ft ² x 4500 ft ² =	19,575
Patching of floors ^{a,c} \$4.94/ft ² x 3600 ft ² =	17,784
Landfilling debris ^d \$12/ft ³ x 1350 ft ³ =	16,200
Level C protective gear	<u>1,000</u>
TOTAL OPERATING COSTS	59,455

^a Includes labor, equipment, materials, overhead, and profit.

^b Reference 4.

^c Reference 3.

^d Estimate.

The rental cost for a 200-gal/h steam cleaner was taken from Means.³ It was estimated that this cleaner could treat 100 ft²/h of surface. Thus, the number of man-hours required to decontaminate the model building would be:

$$\frac{8100 \text{ ft}^2}{100 \text{ ft}^2/\text{h}} = 81 \text{ h or } \sim 11 \text{ days}$$

The following amount of contaminated, condensed steam would have to be collected:

$$200 \text{ gal/h} \times 81 \text{ h} = 16,200 \text{ gal}$$

This contaminated water would be collected in a sump. A pump would be needed to remove the water from the sump to a storage tank at a rate of 200 gal/h. The tank should hold about one day's supply or:

$$200 \text{ gal/h} \times 8 \text{ h} = 1600 \text{ gal}$$

Thus, a 2000-gal tank would be required.

A bulk disposal cost was assumed for this hazardous liquid, at an estimated \$0.50/gal.

A summary of costs is given in Table C-12.

Acid Etching (Method 15)

Acid etching would be used to treat the walls and floors of the model building; therefore, the area to be cleaned would be 8100 ft².

In this cost analysis, a commercial technique of acid etching/washing was assumed. This method would preclude the need for a neutralizing wash following the acid wash; a simple water rinse would suffice. A cost for the treatment was found in Means,³ and it includes labor, equipment, materials, overhead, and profit. It was assumed that the water wash was also included in this cost figure.

An estimated 1/3 gal of contaminated liquid/ft² of treated surface is generated by this process (including both acid etching and the rinse wash). Therefore, the total amount of hazardous liquid requiring disposal would be:

$$8100 \text{ ft}^2 \times 0.33 \text{ gal/ft}^2 = 2700 \text{ gal or } 361 \text{ ft}^3$$

A pump would be needed to transfer this liquid from the sump (where it is collected) to drums for disposal.

A summary of costs is given in Table C-13.

TABLE C-12. STEAM CLEANING COST ANALYSIS
(1984 dollars)

Item	Cost, \$
<u>Operating costs</u>	
Labor	
Setup and tear-down of equipment ^a	
1 h/day x 11 days	11 h
Steam cleaning of walls and floors ^a	
81 h/building	<u>81 h</u>
	92 h
At \$12/h, labor cost = 92 h x \$12/h =	1,104
Overhead	
At 4 x labor cost = 4 x \$1,104 =	4,416
Other operating costs	
Steam cleaner rental ^b	
\$40/day x 11 days =	\$ 440
Disposal of hazardous liquid (in bulk) ^a	
\$0.50/gal x 16,200 gal =	8,100
Level C protective gear	<u>1,000</u>
	<u>9,540</u>
TOTAL OPERATING COSTS	15,060
<u>Capital costs</u>	
Sump pump (200 gal/h)	\$ 700
Storage tank (2000-gal)	<u>7,000</u>
TOTAL CAPITAL COSTS	<u>7,700</u>
TOTAL COST OF STEAM CLEANING	22,760

^a Estimate.

^b Reference 2.

TABLE C-13. ACID ETCHING COST ANALYSIS
(1984 dollars)

Item	Cost, \$
<u>Operating costs</u>	
Acid washing and rinsing of walls and floors ^{a,b}	
$\$0.55/\text{ft}^2 \times 8100 \text{ ft}^2 =$	\$ 4,455
Disposal of hazardous liquid ^c	
$\$12/\text{ft}^3 \times 361 \text{ ft}^3 =$	4,332
Level C protective gear	<u>1,000</u>
TOTAL OPERATING COSTS	9,787
<u>Capital costs</u>	
Sump pump ^c	\$ 300
TOTAL CAPITAL COSTS	<u>300</u>
TOTAL COST OF ACID ETCHING	10,087

^a Includes labor, equipment, materials, overhead, and profit.

^b Reference 2.

^c Estimate.

Appendix C: Cost Analysis

Bleaching (Method 16)

Bleaching would be used to clean the concrete floors and walls of the model building; therefore, the area to be treated would be 8100 ft².

It was assumed that the bleach solution (10 percent sodium hypochlorite) would be applied manually. One gallon of the solution was assumed to be sufficient to treat 1 yd² of the concrete surface; thus, the total amount of solution required to treat the building would be:

$$8100 \text{ ft}^2 \times 1 \text{ yd}^2/9 \text{ ft}^2 \times 1 \text{ gal}/1 \text{ yd}^2 = 900 \text{ gal}$$

After the bleaching treatment, an estimated 2 gal of water would be required to rinse each yd² of surface. Thus, the total amount of contaminated liquid to be collected would be:

$$900 \text{ gal bleach solution} + (2 \times 900 \text{ gal rinse}) = 2700 \text{ gal or } 361 \text{ ft}^3$$

This contaminated liquid would be collected in a sump. A small pump would remove the water and bleach solution from the sump and transfer it to drums for disposal.

A summary of costs is given in Table C-14.

Flaming (Method 17)

Flaming would be used for surface decontamination of the concrete walls and floors in the model building; therefore, the total area to be treated would be 8100 ft².

If a hand-held torch were used to flame the interior concrete surfaces of the building, the rate of decontamination would be about 400 ft²/h. Thus, the number of hours required for decontamination of the model building would be:

$$\frac{8100 \text{ ft}^2}{400 \text{ ft}^2/\text{h}} = 21 \text{ h or } \sim 3 \text{ days}$$

After the flaming effort, labor time was allowed for wash-down of the concrete. The purpose of the wash-down is to allow the concrete to regain strength.

A summary of costs is given in Table C-15.

Drilling and Spalling (Method 18)

Drilling and spalling would be used to remove the contaminated surface of both concrete walls and floors. The drilling and spalling rig can remove 1 to 2 in. of surface; 2 in. is assumed here. Because the 2nd floor of the

TABLE C-14. BLEACHING COST ANALYSIS
(1984 dollars)

Item	Cost, \$
<u>Operating costs</u>	
Labor	
Bleaching of floors and walls (includes application, scrub, and rinse) ^a	
162 h/building 162 h	
At \$12/h, labor cost = 162 h x \$12/h =	1,944
Overhead	
At 4 x labor cost = 4 x \$1,944 =	7,776
Other operating costs	
Bleach solution ^b	
\$0.90/gal x 900 gal = \$ 810	
Disposal of hazardous liquid (by drum) ^a	
\$12/ft ³ x 361 ft ³ = 4,332	
Level C protective gear 1,000	
	<u>6,142</u>
TOTAL OPERATING COSTS	15,862
<u>Capital costs</u>	
Sump pump ^a \$ 300	
TOTAL CAPITAL COSTS	<u>300</u>
TOTAL COST OF BLEACHING	16,162

^a Estimate.

^b Vendor quote.

TABLE C-15. FLAMING COST ANALYSIS
(1984 dollars)

Item	Cost, \$
<u>Operating costs</u>	
Labor	
Setup and tear-down of equipment ^a	
1 h/day x 3 days = 3 h	
Flaming of walls and floors ^a	
1 h/400 ft ² x 8100 ft ² = 21 h	
Cleanup (rinse) ^a	
10 h/building 10 h	
34 h	
At \$12/h, labor cost = 34 h x \$12/h =	408
Overhead	
At 4 x labor cost = 4 x \$408 =	1,632
Other operating costs	
Flamer rental (includes gas consumption) ^b	
\$4.35/h x 21 h = \$ 92	
Level C protective gear 1,000	
	<u>1,092</u>
TOTAL OPERATING COSTS	3,132

^a Estimate.

^b Reference 2.

model building is too thin (4 in.) to withstand treatment, it will have to be demolished and then rebuilt. Thus, the total area to be drilled and spalled would be 6300 ft².

The Decommissioning Handbook⁴ defined a typical drilling and spalling crew to consist of five laborers and a front-end loader.

The working rate of the machine is 67.5 ft²/h. The number of hours and days that would be required for the process would be:

$$\frac{6300 \text{ ft}^2}{67.5 \text{ ft}^2/\text{h}} = 94 \text{ h or } \sim 12 \text{ days}$$

The amount of debris generated by this method would include the 2 in. of concrete removed from walls and the first floor and the concrete from the demolished second floor. The volume of concrete removed from the walls and floor was assumed to expand by a factor of 2. The volume of the demolished floor was assumed to expand by a factor of 3. Thus the appropriate volume of debris would be:

$$6300 \text{ ft}^2 \times 2 \text{ in.} \times 1 \text{ ft}/12 \text{ in.} \times (2) + 1800 \text{ ft}^2 \times 4 \text{ in.} \times 1 \text{ ft}/12 \text{ in.} \times (3) = 3900 \text{ ft}^3$$

Because the drilling and spalling process leaves behind a rough and uneven surface, additional cost would be incurred to patch the floor and walls.

A summary of the costs is given in Table C-16.

TABLE C-16. DRILLING AND SPALLING COST ANALYSIS
(1984 dollars)

Item	Cost, \$
<u>Operating costs</u>	
Labor	
Setup and tear-down of equipment ^a	
1 h/day x 12 days = 12 h	
Drilling and spalling of walls and floors (including cleanup of rubble) ^b	
94 h/laborer x 5 laborers = 470 h	
	482 h
At \$12/h, labor cost = 482 h x \$12/h =	5,784
Overhead	
At 4 x labor cost = 4 x \$5,784 =	23,136
Other operating costs	
Front-end loader rental (2.25-yd ³) ^c	
\$448.40/day x 12 days = \$ 5,381	
Demolition of second floor (including cleanup) ^{c,d}	
\$2.23/ft ³ x 1800 ft ³ = 4,014	
Reconstruction of second floor ^{c,d}	
\$1.30/ft ³ x 1800 ft ³ = 2,340	
Patching of first floor ^{c,d}	
\$4.94/ft ² x 1800 ft ² = 8,892	
Patching of walls ^{c,d}	
\$4.35/ft ² x 4500 ft ² = 19,575	
Landfilling of debris ^a	
\$12/ft ³ x 1650 ft ³ = 19,800	
Level C protective gear 1,000	
	<u>61,002</u>
TOTAL OPERATING COSTS	89,922
<u>Capital costs</u>	
Drilling and spalling rig (including positioning equipment) ^{a,b} \$20,000	
TOTAL CAPITAL COSTS	<u>20,000</u>
TOTAL COST OF DRILLING AND SPALLING	109,922

^a Estimate.

^b Reference 4.

^c Reference 3.

^d Includes labor, materials, equipment, overhead, and profit.

TABLE C-17. METRIC CONVERSION FACTORS
(U.S. CUSTOMARY UNITS TO SI UNITS)

To convert the U.S. customary unit	To the SI Unit	Multiply by
<u>Area</u>		
ft ²	m ²	9.2903×10^{-2}
<u>Length</u>		
ft	m	0.3048
in.	cm	2.54
<u>Mass</u>		
lb	kg	0.4536
ton (2000 lb)	Mg	0.9072
<u>Pressure</u>		
lb/in. ²	kPa	6.8948
<u>Volume</u>		
ft ³	m ³	2.8317×10^{-2}
gal	liter	3.7854

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APPENDIX D

CASE STUDY: SEVESO, ITALY

BACKGROUND

On July 10, 1976, an explosion at the ICMESA (Industrie Chimich-Meda-Società Azionaria) chemical factory in the municipality of Meda, which borders the town of Seveso, Italy, released a cloud of toxic chemicals that contaminated the surrounding community with tetrachlorodibenzo-p-dioxin (TCDD) and other pollutants. The ICMESA plant is owned by the Givaudan Corporation, a subsidiary of the Switzerland-based Hoffman-LaRoche pharmaceutical company. Trichlorophenol (TCP), a starting material in the manufacture of hexachlorophene (a disinfectant), was produced at the ICMESA facility for export to Givaudan's plant in Clifton, New Jersey.

Givaudan's patented method of TCP production involves partially hydrolyzing tetrachlorobenzene to sodium trichlorophenate with sodium hydroxide in a mixed solvent of xylene and ethylene glycol. Unreacted glycol is subsequently recovered by distillation. When distillation is complete, water is introduced into the reaction vessel and the entire mass is transferred to a second reactor. Trichlorophenate is then transformed to TCP by acidification with hydrochloric acid. A full production cycle can be completed in 24 h (three 8-h work shifts).

Tetrachlorodibenzo-p-dioxin is formed as an unwanted byproduct during the synthesis of TCP by thermal condensation of trichlorophenate at temperatures above 180°C. During the tetrachlorobenzene hydrolysis reaction process at the ICMESA facility, batch temperatures were maintained at 140° to 150°C. Whenever reactor temperatures approached the danger threshold, further increases were limited by manually opening a valve to introduce water into a cooling coil. The ICMESA plant was not equipped with automatic alarm devices to signal unusual events in the production cycle or safety devices to halt the cycle if necessary.

The ICMESA factory explosion occurred in a 10-m³ reactor (designated A101) in Building B of the plant. At about 5:00 a.m. on Saturday, July 10, workers began shutting down the production cycle for the weekend. At that point, distillation of the ethylene glycol solvent was only one-third complete. Interrupting the cycle before distillation had been completed and washdown procedures had begun was not part of the normal operating routine.

Because it was the weekend, only a few watchmen and maintenance people were in the plant when, at 12:40 p.m., an exothermic reaction (cause unknown)

Appendix D: Seveso, Italy

raised the reactor temperature and pressure beyond limits and caused a reactor safety valve pressure disk to rupture. Under the thrust of the built-up pressure, part of the reactor contents were expelled through the valve orifice at the top of the tank, which was vented to the open air. (The plant was not equipped with a collection and abatement system for substances that could potentially be released in the event of an accident, as Italian law requires.) A visible plume, which rose to a height of approximately 50 m, was dispersed by a light wind before it descended and settled over an area southeast of the plant.

The ICMESA plant is situated in an enclave of former farmland surrounded by a densely populated suburban area incorporating the towns of Seveso, Cesano Maderno, Meda, and Desio. The inhabitants of the area are primarily artisans from southern Italy and their families. (Seveso's main industry is furniture making.) A heavily traveled freeway running northward from Milan to the Swiss border skirts the ICMESA plant to the east.

Houses on the fringes of the large business districts are primarily two-story detached dwellings of stuccoed cement block with red tile roofs. Many of the homes were built by their owners. The area also has several two- to four-story cement-block apartment buildings, schools, and small and medium-sized artisan shops. All houses, schools, and other buildings in the path of the TCDD-containing cloud were contaminated as a result of aerial deposition.

The explosion in Reactor A101 also contaminated Building B of the ICMESA factory. The TCP production plant, which was located at one end of the building, occupied two interconnecting rooms. A third room was occupied by the distillation plant. The results of various investigations indicated that the TCDD was confined to a few vessels and interconnecting pipes; the remaining equipment was nominally clean on the inside, although some external contamination was evident. Contamination was also present on the building roof and exterior walls.¹

NATURE AND EXTENT OF CONTAMINATION

The fact that local health and labor authorities had never been informed of the TCP production activities at the ICMESA plant contributed to the apparent lack of immediate understanding of the nature and seriousness of the emergency and the extent of the area that was contaminated.

Contaminants Present

Much of the area upon which the toxic cloud descended consisted of garden plots and fields for growing crops and grazing cows. The fallout affected leaves, vegetables, and grass, as evidenced by withering, burns, and yellow spots. Within a few days, small animals (rabbits, birds, mice, chickens, and cats) began to sicken and die. At the time of the explosion, most

of the people were indoors for their noon meal, but those who had been exposed to the strongly alkaline cloud (mainly children) developed burnlike dermal lesions. Nine days after the accident, Givaudan administrators informed Italian health officials that TCDD contamination had been found in samples of soil and vegetation collected near the ICMESA plant (after the explosion) and analyzed at Givaudan laboratories in Switzerland.²

Sampling and Analysis

The nature of the contamination resulting from the explosion at the ICMESA plant was such that all exposed surfaces in the area were affected. Both soil and building contamination are addressed in this case study because of their interdependence.

Soil--

To define the extent of TCDD contamination, investigators took superficial soil samples at 50- to 100-m intervals along five radial lines extending southward from the ICMESA facility. A higher sampling frequency was used within 0.6 km of the contamination's origin, where initial monitoring indicated greater concentrations of TCDD. Triplicate samples were taken at sites in open meadows and agricultural fields; two of the sample specimens were combined for analysis, and the third was reserved as a reference. Sampling was achieved by sinking steel cylinders (0.6 m long, 7-cm i.d.) vertically into the soil to a depth of a few centimeters. Core samples were subsequently retrieved and stored in sealed plastic bags.^{3,4} The procedures adopted for the analysis of TCDD in soil involve combined gas chromatography/mass spectrometry and have been described by di Domenico et al.⁴

Based on the results of the soil survey, three contamination zones (designated A, B, and R) were defined (Figure D-1). Zone A (110 ha), which contained most of the escaped TCDD (approximately 2 to 3 kg), is located south-southeast of the ICMESA plant, in the same direction as the dominant wind at the time of the accident. Zone A was further divided into Subzones A1 through A8 (numbered according to their distance from the plant) based on topographical and municipality features. Zone B (170 ha) is the natural extension of Zone A along the main diffusion pathway of the TCDD-containing cloud. An estimated 20 g of TCDD was deposited in Zone B. Both Zone A and Zone B are surrounded by a larger Zone of Restriction (1430 ha), which contained an additional 20 g of TCDD. The TCDD concentration in the soil at the borderline between Zone A and Zone B was set at 50 $\mu\text{g}/\text{m}^2$, whereas the concentration between Zone B and Zone R was set at 5 $\mu\text{g}/\text{m}^2$. Zone R includes all the remaining areas where detectable levels of TCDD ($>0.75 \mu\text{g}/\text{m}^2$) were found.^{3,6}

Building Surfaces--

The extent of contamination on interior surfaces of houses, schools, and other buildings was established by means of swab tests on walls, floors, and windows.⁴ Only smooth, solid, nonabsorbing surfaces such as polished marble, waxed stoneware, ceramic tile, glass panes, formica, and varnished metal and wood were wiped.

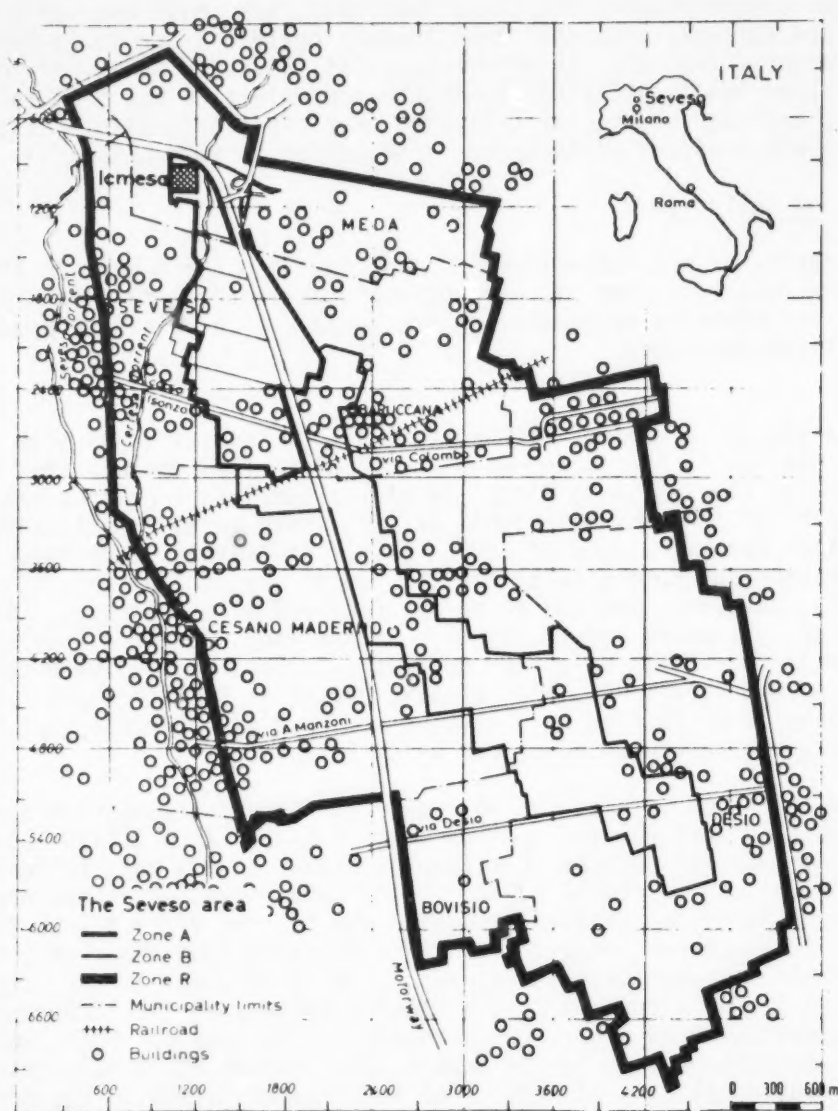


Figure D-1. Zones A, B, and R, showing major built-up areas (O) and surrounding farm lands. The ICNESA plant appears within Meda municipal boundaries near the Meda-Seveso borderline. Most of Zone A lies within the Seveso Municipal boundaries, while Zone B comes within the Cesano Maderno and Desio municipal boundaries.

Source: Reference 5.

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Sampling areas on walls were chosen within child's reach (i.e., less than 1.5 m above ground). Sampling areas on inside floors were generally chosen in halls, near entrances, in restrooms, and near windows facing in the direction of the ICMESA plant (personal communication from A. di Domenico, Istituto Superiore de Sanità, Roma, Italy, June 25, 1984).

A square sampling area of 0.25 m² was wiped back and forth, vertically and horizontally, with a 10-g degreased cotton swab saturated with 20 to 30 ml of a 1:4 acetone/hexane mixture. (Cotton swabs were degreased by prolonged Soxhlet extraction with hexane previously deprived of GC/ECD-responding compounds.) Before changing wiping directions, the swab was turned over to present a clean surface for wiping. The cotton swab was held in a clean metal clamp while sampling was performed and stored in a glass-stoppered glass jar prior to extraction. (The jars, normally of dark glass, were cleaned by repeated washing with purified hexane.) Used cotton swabs were extracted three times with 200 ml of the acetone/hexane solvent. The three extracts were pooled, dried under vacuum, and treated as described for soil extracts by di Domenico et al.⁴

The extent of TCDD contamination on exterior building surfaces was established by scraping off the top layer (1 to 2 mm) of a square 0.25-m² area using steel hand scrapers (similar to the spatulas used by building workers). Normally, painted walls were avoided. Scraping samples (100 to 500 g) in the form of coarse dust were collected and stored in clean, dark glass jars. Extraction was achieved by mixing the scrapings with anhydrous Na₂SO₄ and shaking vigorously with three fractions (400, 300, 300 ml) of a 1:4 acetone/hexane mixture. The three fractions were pooled, evaporated to dryness, and analyzed by the method described by di Domenico et al.⁴

Interior and exterior building surfaces in Subzones A6 and A7 were not extensively monitored prior to the initiation of decontamination efforts. Available information, however, indicated that TCDD contamination was very unevenly distributed.⁷ Maximum contamination on interior surfaces was found to be 2 to 3 µg/m² TCDD while exterior building surfaces (on walls facing the ICMESA plant) were contaminated with up to 5 µg/m² TCDD (personal communication from G. U. Fortunati, Regione Lombardia, Seveso, Italy, July 3, 1984).

Health Hazard Evaluation

Accidents similar to the one at the ICMESA factory have also occurred at other TCP production facilities (in the United States, Germany, England, and Holland). In each of these cases, however, contamination was contained within the factory. The accident at Seveso marks the first time that contamination was dispersed over a wide area and affected the lives of thousands of people.

Appendix D: Seveso, Italy

Tetrachlorodibenzo-p-dioxin is extremely toxic, even at very low concentrations. The oral LD₅₀ for male and female guinea pigs is 0.0006 to 0.0021 mg TCDD/kg of body weight.⁸ Virtually insoluble in water (0.2 µg/liter), TCDD has a high affinity for soil colloids and particles and is extremely persistent in the environment. It can be absorbed through the skin, inhaled, or ingested. Symptoms of TCDD poisoning in humans include chloracne, liver and kidney ailments, and nervous disorders. This substance is an established teratogen and a suspected carcinogen.

Preliminary analytical findings from soil and vegetation samples plus available information on the occurrence of toxic and pathological events and on air movements at the time of the explosion prompted Italian authorities to evacuate the 739 inhabitants of Zone A. The evacuation took place in three stages (July 26, 28, and August 2).^{*} Evacuees were officially forbidden to remove household goods or any but their most essential personal possessions. They were given allowances by the provincial authorities and housed temporarily in a large apartment and hotel complex near Milan. Access to Zone A was restricted by construction of a barbed wire fence around its perimeter. The fence was guarded and patrolled continuously by carabinieri (military police who were also entrusted with civil police duties).

Although inhabitants of Zones B and R were not evacuated, children under 12 and women up to 3 mo pregnant were removed during the day to reduce their exposure to the contamination. Residents were instructed to follow several hygienic rules and were temporarily advised against conceiving children. Strict measures concerning food and water supplies were adopted. Orchards were destroyed, and all edible animals were taken away or killed after reimbursement. Cultivation and animal breeding, as well as new construction, were prohibited or severely restricted. Because inhabitants of Zones B and R were assumed to be chronically exposed to low levels of TCDD, they were placed under medical and epidemiological surveillance along with the former inhabitants of Zone A.

DECONTAMINATION STRATEGY

Reclamation of the contaminated area was particularly urgent for Sub-zones A6 and A7, areas in which approximately two-thirds of the evacuees had been living before the accident. The average and peak TCDD levels in Sub-zones A6 and A7 were lower than those in other parts of Zone A.²

^{*} Lombardy Regional Law No. 2 of January 17, 1977 established 50 µg TCDD/m² of soil as the limit above which the area was to be barred to human inhabitants.⁹

Target Levels

Target levels for TCDD in soil and on building surfaces were established by the Lombardy Regional Authority as follows:⁷

- ° Soil, top 7 cm: $<5 \mu\text{g}/\text{m}^2$
- ° Exterior building surfaces: $<0.75 \mu\text{g}/\text{m}^2$
- ° Interior building surfaces: $<0.01 \mu\text{g}/\text{m}^2$

Decontamination Methods

To a large extent, decontamination of the Seveso homes, schools, and other buildings was dependent on reducing the TCDD concentration in the surrounding soil; thus decontamination of both the soil and buildings are discussed.

Soil--

Following the Seveso incident, a search of the literature revealed that TCDD degrades rapidly in ultraviolet light, given the presence of a hydrogen donor. Experiments carried out by Givaudan and controlled by the Istituto Superiore di Sanità (ISS), in which an oil emulsion was sprayed on contaminated vegetation, indicated that the TCDD level could be reduced by 50 percent in 24 h.⁶ Heavy fall rains, however, washed the TCDD from the vegetation into the soil before widespread decontamination efforts could be attempted.

Penetration of TCDD into the soil occurred very slowly. Most of the contamination was found to be concentrated in the top 15-cm soil layer. Available data indicate that a statistically significant reduction of TCDD levels in the unworked soil of Zone A occurred in the first 5 mo. After this period, no further decrease in TCDD levels was detected.⁵ The initial reduction of TCDD observed in Zone A has been attributed to photodegradation in the topmost soil layer and to volatilization through different channels, the extent of which have decreased with time. In situ treatment of TCDD-contaminated soil by microbial action was considered, but the ISS was unsuccessful in its attempts to find microorganisms capable of degrading TCDD in soil or organic substances that could stimulate the growth of naturally occurring microbial flora.⁶

Among the several alternative strategies for disposing of the dioxin-contaminated soil considered in the first months following the accident were incineration at sea, direct ocean dumping, and deep disposal in a salt pit. International conventions governing the use of the seas and public opposition to the latter made these strategies impractical. The most practical solution, and the one subsequently approved by the regional authorities, was high-temperature incineration of the soil in a rotary kiln constructed in the more heavily contaminated area of Zone A. Strong public opposition based on the fear that some dioxin might escape from the incinerator stack and that Seveso would become a dumping ground for all of Italy eventually forced abandonment of these plans, however.

Appendix D: Seveso, Italy

Reclamation of the highly contaminated soil ($>5 \mu\text{g}/\text{m}^2$) of Zone A has largely been accomplished by surface stripping and replacement with clean soil. The contaminated soil has been trucked to Subzone A5 for disposal in huge concrete-lined bunkers. In the less-contaminated areas, deep ploughing of the top 30 cm of soil has resulted in a 40 percent decrease in TCDD concentration over 3 yr (1976/77 to 1979/80).⁵

Houses--

No single decontamination technique was found to be universally applicable to the variety of building materials used for domestic dwellings; therefore, an integrated approach was used to reclaim the Seveso homes contaminated with TCDD. This approach involved 1) removal of contaminated items, 2) cleaning of surfaces to an acceptable level, and 3) sealing in of residual contamination.

Thirty-six houses in the area of highest soil contamination, which were considered too polluted to be cleaned, had to be demolished; new replacement homes were constructed nearby. One hundred and twelve houses in the less contaminated areas (Subzones A6 and A7) were extensively decontaminated. Roof tiles were replaced, and both interior and exterior walls were vacuumed. Smooth, nonabsorbing surfaces were washed with surfactants and common solvents, whereas wall plaster and wooden floors were subjected to various degrees of scraping. Linoleum floors, wallpaper, furniture, and loose objects that could not be cleaned were removed and placed in concrete-lined pits in Subzone A5, along with the contaminated roof tiles. Many interior surfaces were subsequently coated with paint or varnish. Toxic waste that had been washed from the interior walls was collected in concrete-lined tanks placed outside the houses being cleaned. The tanks then were taken by truck to be emptied elsewhere, or the waste in them was pumped to a field lying just within Subzone A5.

The top layer of soil in orchards, gardens, and the immediate external surroundings was normally scarified to a depth of at least 20 cm. The contaminated soil was trucked to Subzone A5 and replaced with an equivalent amount of clean soil.

Schools--

Regional authorities made a concerted effort to decontaminate the schools so that the children could return to them. Remedial measures were similar to those taken for houses. In September 1976, after the walls had been vacuumed and washed with detergents, all schools were declared free of traces of dioxin.¹⁰ In February 1977, however, a number of children in six schools in Zone R developed suspected cases of chloracne. Epidemiologists suspected that children had tracked dioxin into classrooms on the soles of their shoes. The schools that were found to be contaminated were closed so they could be cleaned.

During the summer of 1977, regional authorities did not conduct any type of systematic measurement of dioxin levels in schools in Zone B. Decontamination operations were carried out only sporadically. As the beginning of

the new school year approached, a considerable number of schools were discovered to be contaminated with significant traces of dioxin (this included some that had been pronounced dioxin-free earlier in the year).¹⁰ Of 139 schools tested, 124 had to be closed until decontamination procedures could be carried out.

Trichlorophenol Plant--

One week following the explosion, the mayor of Meda issued an ordinance to close down the production sections of the ICMESSA plant, which had continued to operate. In addition, the Givaudan company was ordered to begin decommissioning Building B of the plant. At that time, Reactor A101 was estimated still to contain 250 to 300 g of TCDD.¹

In 1978, Givaudan retained the Hazardous Materials Service (HMS) of the Harwell Laboratory, U.K., to prepare a feasibility study on remedial measures.¹ Three methods were proposed by HMS for the decontamination, dismantling, and disposal of the TCP plant within the ICMESSA factory:

1. Construction of a giant monolith to entomb the entire plant.
2. Comprehensive decontamination of the plant, followed by dismantling and disposal of the clean equipment and disposal of the contaminated wastes.
3. Dismantling of the plant in such a way that highly contaminated materials would be contained within the vessels and pipes, followed by direct disposal of the contaminated equipment.

Each of these methods was considered in turn, and each is explained briefly.

Monolith--Construction of a monolith involves casting the building and equipment in concrete. The principal advantage of this approach is that virtually all worker contact with contaminated equipment or surfaces is eliminated once the loose debris has been cleared and the surfaces have been coated with lacquer (to prevent migration of contamination during the effort). Disadvantages are numerous, however. Technically, it may be difficult to ensure that pipes are not broken while the concrete is being poured and is setting. The effects of weathering and/or flooding might lead to fissuring of the concrete and water ingress. Environmentally, the monolith would be aesthetically unattractive and would afford only a temporary solution.

Comprehensive decontamination--Various techniques are available for the decontamination of external surfaces, but they are either difficult to apply to complex equipment and inaccessible surfaces (e.g., mechanical methods, vacuuming), or they pose a high risk of worker exposure to toxic chemicals (e.g., solvent or steam cleaning). Decontamination of the interior of the reactor and its associated vessels and pipes poses an even greater problem.

Appendix D: Seveso, Italy

The contents of the reactor have set solid, and it is unlikely that water or solvent cleaning would be effective; some form of mechanical removal would be necessary, and this would be difficult to achieve safely. Similarly, some of the pipes contain tarry deposits that would be difficult to remove. Even if the contents could be safely removed, the internal surfaces would still have to be decontaminated. Because the success of such an operation would be difficult to monitor, it would still be necessary to dispose of the equipment as if it contained some residual contamination. Comprehensive decontamination generates large quantities of highly contaminated liquid wastes for disposal and maximizes worker exposure to contamination.

Dismantling--In this method, no attempt is made to remove contaminated solids from the vessels and pipes. Rather, the plant is dismantled and disposed of directly. The main advantage of this approach is that handling of contaminated materials is minimized. Furthermore, liquid wastes are not generated; considering the unavailability of incinerators capable of destroying such wastes, this presents an additional advantage over the comprehensive decontamination option.

The feasibility study identified dismantling as the most practical remedial alternative. Stepwise instructions outlined by HMS for the controlled dismantling of the TCP plant are as follows:¹

1. Removal of lagging. Dust control techniques similar to those for removal of asbestos should be employed.
2. Vacuuming of loose dust. All surfaces should be sealed with a coat of paint or lacquer to minimize dust and contamination problems.
3. Removal of the plant and ancillary equipment. The services and relatively uncontaminated pipework should be removed first and the heaviest and most highly contaminated items left to the end. Vessels known to contain liquids will need to be drained into drums. Because of the presence of flammable solvents, special techniques and precautions will be needed when any items have to be cut open or into pieces.
4. Decontamination or demolition of the building shell.

The Givaudan Corporation is proceeding with the dismantling and disposal of contaminated equipment. The distillation plant has already been removed from Building B. As equipment is removed, it is to be encapsulated in specially designed containers for disposal in a remote, geologically secure site (which has not yet been chosen).

Worker Protection

Most of the decontamination work force has been supplied by a contractor in Milan. All workers are required to enter the fenced-off area of Zone A

through a filter station, where they change into impermeable suits, boots, and hoods and don face masks with filters. At the end of the work shift, workers must shower before changing back into street clothes. Discarded decontamination suits are placed in plastic containers for removal (by the next work shift) to contaminated material dumps in Subzone A5.

All workers operating in the contaminated zones were given preemployment physical examinations to ascertain their fitness. Based on the same selection criteria, a control group was chosen from employees of the same firm. Medical examinations and laboratory tests were performed on both the exposed and nonexposed groups 9 and 6 months, respectively, after their first examinations. No differences between these groups were found.¹¹

Plans for decommissioning Building B require that workers wear fully encapsulating suits fitted with a two-way communication system and supplied with air by a trailing hose. The affected rooms will be maintained under negative pressure, and the extracted air will be passed through efficient dust filters.

Costs

Hoffman-LaRoche has assumed financial responsibility for all aspects of the cleanup and for victim compensation. Approximate figures for the decontamination of houses in Subzones A6 and A7 and for the TCP plant are \$2.5 million and \$3.0 million, respectively (personal communication from G. U. Fortunati, Regione Lombardia, Seveso, Italy, July 3, 1984). The total bill is expected to exceed \$130 million.¹²

EVALUATION OF DECONTAMINATION EFFECTIVENESS

The buildings in Subzones A6 and A7 were extensively monitored throughout the course of decontamination. Figure D-2 shows the distribution of TCDD levels detected on interior surfaces following the first level of decontamination effort.⁷

The uneven distribution of TCDD on building surfaces made assessment of the effectiveness of decontamination operations a difficult task. Consequently, Subzones A6 and A7 were further subdivided into clusters of buildings with more homogeneous TCDD levels and distribution patterns. Three building clusters were identified (Figure D-3) on the basis of the following criteria:

- ° Building location with respect to the path of the TCDD-containing cloud
- ° Topographical features
- ° TCDD levels detected on interior and exterior building surfaces

Appendix D: Seveso, Italy

After the decontamination treatments were completed, a minimum of 113 random samples were taken from interior building surfaces in each cluster and analyzed for TCDD. All values were within the maximum permissible level of TCDD ($0.01 \mu\text{g}/\text{m}^2$). Similar results were obtained on samples taken from exterior building surfaces.⁷

Decontamination operations were reiterated until target levels for TCDD on building surfaces and in soil were achieved (up to four cycles for agricultural soil in Zone A). Subzones A1 through A5 remain sealed off, but residents of Subzones A6 and A7 were permitted to return to their homes in the fall of 1977, 17 mo after the ICMESA factory explosion.

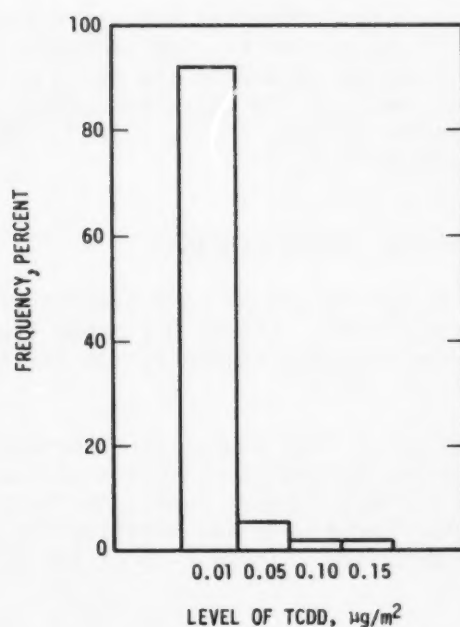


Figure D-2. TCDD concentrations found on internal building surfaces of Subzones A6 and A7 following completion of the first level of decontamination.

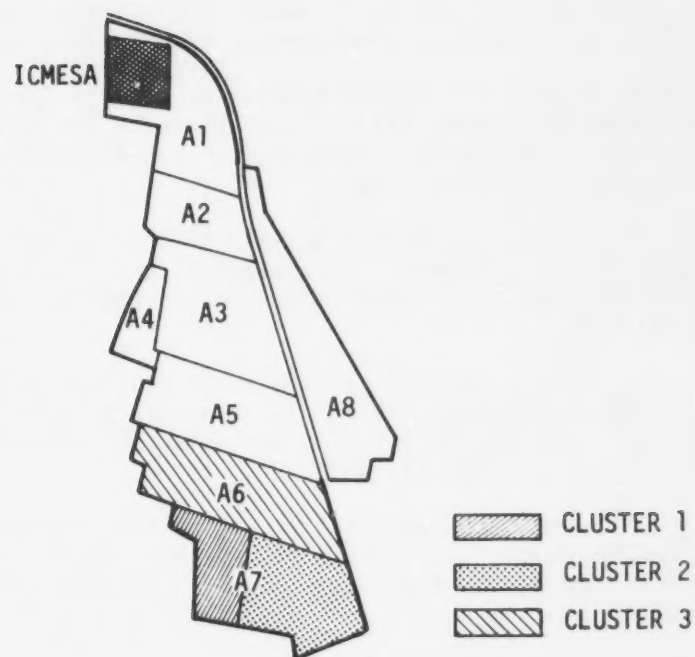


Figure D-3. Building clusters within Subzones A6 and A7.

Source: Reference 7.

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APPENDIX E

CASE STUDY: BINGHAMTON STATE OFFICE BUILDING

BACKGROUND

On February 5, 1981, an electrical fire occurred in the basement of the 18-story Binghamton State Office Building (BSOB) in Binghamton, New York. The excessive heat caused an electrical transformer to fail and release an estimated 680 to 760 liters of fluid containing 65 percent polychlorinated biphenyls (PCB's) and 35 percent chlorinated benzenes (Arochlor 1254). Pyrolytic conversion of these substances resulted in the formation of tetrachlorodibenzodioxin (dioxin) and tetrachlorodibenzofuran (furan). Although the fire itself was contained in the basement, black soot containing PCB's, dioxin, and furan was distributed throughout the entire building via the ventilation system. The soot was deposited on all surfaces of the building interior and its furnishings.

Because firefighters and investigators suspected contamination when they detected an acrid odor upon entering the basement, they immediately evacuated the building and donned respiratory equipment before reentering. The building was closed to employees and the public on that day and was still closed as of February 1984.

The building is owned by the State of New York; therefore, the New York State Office of General Services (OGS) has been responsible for any decontamination activities and costs. The selected cleanup contractors were responsible for planning and management of the program and for providing the physical labor for cleanup activities. This site is not on the Superfund National Priorities List.

The decision to decontaminate the BSOB was made because the costs for dismantling this recently constructed building and disposing of the debris in a secure site were prohibitive.

NATURE AND EXTENT OF CONTAMINATION

The nature and extent of contamination were determined by sampling various media for the suspected contaminants.

Contaminants Present

The contamination consisted of polychlorinated biphenyls (PCB's), tetrachlorodibenzodioxin (dioxin), and tetrachlorodibenzofuran (furan). The

contaminants were present in a black soot that was distributed throughout the building. The soot covered all interior surfaces and furnishings and was present in most seams, cracks, crevices, and other small openings.¹

Sampling and Analysis

Variations of both dry-wipe and wet-wipe sampling methods were used for different locations and surface types. For example, the wet-wipe method used for sampling cleaned vinyl flooring involved soaking a sterilized cotton wipe with hexane. A specially designed apparatus was used to hold the wipe in a manner that would minimize cross-contamination and interference by other substances (personal communication from R. Westin, Versar, Inc., Springfield, Virginia, February 27, 1984).

Initial Sampling--

Initial sampling of the building air and soot began the day after the fire and continued for 3 weeks. The samples were collected and analyzed by the New York State Department of Health (DOH). Early test results revealed that the air contained 6 to 62 $\mu\text{g PCB}/\text{m}^3$, and all soot samples contained 10 to 20 percent PCB's.¹ The air levels were below the Occupational Safety and Health Administration (OSHA) allowable standards. Personnel inside the building continued to wear respirators.

The samples that the New York State Department of Environmental Conservation (DEC) took of air outside the building showed no PCB contamination. Water samples from the nearby Susquehanna River were also collected by DEC.

Approximately 3 weeks after the fire, DOH informed OGS that the soot samples they had taken contained dioxins and furans, as well as PCB's.

Ongoing Sampling--

Ongoing testing includes:

- ° Sampling of air released from air pollution control system (APCS) filters.
- ° Sampling of treated wastewater prior to discharge into the Binghamton sanitary sewer system.
- ° Visual inspection of all previously soot-covered surfaces.
- ° Wipe-test sampling of some cleaned areas.
- ° Soot sampling from above ceiling panels and other remote areas.

As of January 1983, DOH had collected and analyzed 265 small bottles and 30 large containers of soot.¹

Health Hazard Evaluation

The U.S. Environmental Protection Agency (EPA) has listed polychlorinated biphenyls and tetrachlorodibenzodioxins as carcinogens. Tetrachlorodibenzofurans have narcotic vapors that can be absorbed through the skin.

DECONTAMINATION STRATEGY

Because of the nature of the contamination at the BSOB, many of the cleanup activities were unprecedented. The decontamination program evolved as various problems were solved by application of the best techniques and materials available at the time.

Target Levels

The current major setback to the release of the BSOB for public use is the lack of a target level for a combination of PCB, dioxin, and furan contamination. The Commissioner of the DOH, who is responsible for establishing the target level, is faced with two major obstacles--no precedent and no predetermined OSHA levels for the contaminants.

The State of California Department of Health Services issued a draft policy on exposure to carcinogens. The guidelines provided therein allow up to a one-in-a-million risk. This policy was used in establishing a target level for the PCB-contaminated One Market Plaza office complex in San Francisco.

In another office building, PCB contamination was cleaned up and the building was released for public use shortly thereafter. In this case, however, wipe sampling showed that PCB's were the only contaminants present; thus, synergistic effects were not a consideration. Also, less contamination was present in that it had only been tracked on the floor as opposed to being distributed via the ventilation system. In this building, achievement of ambient PCB levels was sufficient to warrant release of the building (personal communication from R. Westin, Versar, Inc., Springfield, Virginia, February 27, 1984).

Methods

At the BSOB, the following media had to be decontaminated: inside air; building wastewater; and buildings, structures, and equipment.

Inside Air--

An air pollution control system (APCS) was installed on the BSOB roof in September 1981. The system was designed to remove particulate and vapor phase PCB's and dioxins by drawing air through a series of filters. The air was tested to confirm that the system was operating properly.¹

Building Wastewater--

The BSOB cleanup activities generated large amounts of wastewater. Disposing of used cleaning rags rather than rinsing them reduced the amount of contaminated wastewater generated. A water treatment system established in the subbasement of the building consisted of three above-ground swimming pools, each with a capacity of about 50 m³. Water from the cleanup operations was routed to the first pool, pumped at a high rate through sand filters to remove large particulates, allowed to flow into the second pool, and then channeled through a series of activated-charcoal filters to remove smaller particles. Filtered water flowed by gravity to another pool, where it was tested for composition. Water with a level of contamination within the permit conditions was then released to the Binghamton sanitary sewer system.¹

Buildings, Structures, and Equipment--

Surfaces of buildings, structures, and equipment at the BSOB were decontaminated by scrubbing with rags wetted with an industrial nonionic detergent. The product was chosen because it has been well characterized by bioassay methods and does not cause interference in sample analysis. When this and other commercially available cleaning products proved to be ineffective for cleaning vinyl floor tiles, the flooring was removed and taken to a secure RCRA landfill.

Used cleaning/scrubbing rags were placed directly in drums, which were delivered to a secure landfill. Rinsing and reusing these rags would have created large quantities of contaminated wastewater and could have spread the contamination from one area to another.

The following items associated with the BSOB had to be decontaminated:

- ° Structural appurtenances
- ° Porous materials
- ° Furniture
- ° Office equipment

Methods used for decontaminating each of these items are discussed in the following subsections.

Structural appurtenances--These are items that are structurally associated with the building and essential to its operation.

The thousands of customized ceiling pieces that had to be decontaminated were removed, identified by code number, cleaned by scrubbing with detergent, and reinstalled. Blown insulation above the ceiling panels was vacuumed to remove contaminated soot before the panels were reinstalled.

Over 1000 heating/cooling terminal boxes had to be decontaminated. This entailed opening the boxes, removing the insulation, scrubbing with detergent, and then closing them. This task required many hours because of the limitations in manual dexterity posed by protective equipment.

Appendix E: Binghamton State Office Building

Decontamination of 5000 ceiling light fixtures was another time-consuming task that was also limited by lack of dexterity imposed by the protective equipment. The fixtures were removed from the ceiling and opened. After the lighting element was removed, the fixture and its ceiling tracks were thoroughly cleaned. Approximately 4 h were required for removal, cleaning, and reinstallation of each fixture.¹

Porous materials--The porous materials involved at the BSOB included documents, carpeting, draperies, and floor tiles. All documents on desk tops and in files were shredded, baled, and disposed of in a secure landfill. The carpeting and draperies also were removed and disposed of at the landfill. Originally it was felt that the floor tiles could be decontaminated with detergent, but testing revealed that commercial products could not render the tiles "clean" so they also were disposed of by landfilling.¹

Furniture--When the BSOB cleanup began, all furniture was vacuumed and moved to the basement. Consideration of potential personnel attitudes toward this furniture then prompted the decision to dispose of it. The items involved included:

1950 chairs	190 stools
930 desks	120 racks
850 file cabinets	110 map files
522 tables	100 lockers
325 bookcases	52 benches
310 storage cabinets	50 couches

In addition to the furniture, 400 miscellaneous items and all personal desk-top items were disposed of at a landfill.¹

Office equipment--Decontamination of office equipment and machines would require dismantling, scrubbing, and reassembly. Because of the costs required for such activities, disposal of the following items has been considered:

200 typewriters	15 postage machines
90 recorders	15 computer terminals
40 adding machines	15 copiers
20 postage scales	5 microfiche readers

The cleanup contractor is currently investigating whether cleaning or disposal of the office equipment is more appropriate.¹

Worker Protection

Decontamination of the 18-story BSOB became a large, complex operation. Although OGS represented the building owner (the State of New York), contractors managed the project, provided onsite supervision, and performed daily decontamination activities.

Personnel Training and Supervision--

Before working in the BSOB, decontamination workers must:

- ° Attend a lecture on the health effects of PCB's, dioxin, and furan.
- ° Successfully complete OSHA respirator training and fit test.
- ° Be aware of standard operating procedures.
- ° Complete a walk-through training of procedures.
- ° Undergo a complete physical examination.

Full-time supervision at three levels is provided for employees working in the building.

Safety and Security Considerations--

Because of the large amount of space and the number of people involved in this operation, safety and security had to be top priorities. Although OGS was ultimately responsible for site activities, contractors were responsible for implementing plans and procedures to produce the desired outcome.

Female workers and female visitors are not permitted at this site because of the mutagenic and teratogenic nature of some of the contaminants.

The DOH prepared a safety plan based on the requirements of the Occupational Safety and Health Act (29 CFR). This plan, which addressed security, personal protective equipment, showers, change areas, and sampling schemes, was approved by OGS and the National Institute for Occupational Safety and Health (NIOSH).¹

Medical surveillance program--A medical surveillance program for all employees was instituted 3 yr ago and was still in effect as of February 1984. Bimonthly exams are given to those who still enter the building, and followup exams are provided for those who have completed their assignments within the BSOB.¹

Personal protective equipment--Workers inside the BSOB are required to wear Level C protection, which includes air-purifying respirators with particulate filters, Tyvek suits, gloves, and rubber shoe covers.

Filter cartridges on the respirators originally chosen for use at the site tended to fall out, which caused workers to breathe unfiltered air. These respirators were replaced with another more reliable brand.¹

High temperatures inside the building caused workers to perspire to the point of sometimes breaking their respirator seals. Some employees reportedly lifted their masks to wipe perspiration from their faces.²

Appendix E: Binghamton State Office Building

Controlled entry--An entry module was installed at the basement level loading dock in September 1981. The specially designed trailer provided an area between the contaminated building and the "clean" community where the following took place:

- ° Contaminated equipment and other items removed from the building were decontaminated.
- ° Contaminated disposable clothing was placed in receptacles for later disposal.
- ° Contaminated reusable clothing was laundered.
- ° Employees showered before returning to their homes and communities.

The entry module provided an additional level of protection to prevent contamination from leaving the BSOB.

For prevention of unauthorized entry into the building, round-the-clock security is maintained. A central security office is responsible for monitoring and testing all alarm systems.¹

Costs

As of January 1984, approximately \$10 million had been spent for the cleanup activities. The total effort is expected to cost \$20 to \$21 million (personal communication from R. Westin, Versar, Inc., Springfield, Virginia, February 14, 1984, and February 27, 1984).

EVALUATION OF DECONTAMINATION EFFECTIVENESS

As of February 1984, the effectiveness of the decontamination effort was determined by physical removal of contaminated soot and random sampling of various media. Because target levels have not yet been established, no further determination of the cleanup effectiveness can be made.

REFERENCES FOR APPENDIX E

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APPENDIX F

CASE STUDY: SONTAG ROAD AREA

BACKGROUND

In 1971-72, portions of a major county roadway and adjacent privately owned access areas in a small community in southwestern St. Louis County, Missouri, were sprayed with dioxin-contaminated waste oil for dust control. Vehicular and pedestrian traffic in combination with natural transport processes spread the material over a county road intersection, over approximately 1500 m of roadway, and into yards and residences of nearby homeowners, businesses, and public buildings. The Sontag Road area includes site locations known as Castlewood Pool, Waterman Road, Mel's Tavern, Horsefalls Residence, and Vespy Residence.

NATURE AND EXTENT OF CONTAMINATION

The Sontag Road area is one of more than 35 confirmed dioxin-contaminated sites in central and eastern Missouri. The Bliss Salvage Oil Company sprayed these areas for dust control, primarily in 1971 and 1972. A poisoning episode at three riding stables in the summer of 1971, which killed more than 60 horses and hundreds of birds, cats, and dogs, led investigators from the Missouri Department of Health and the Centers for Disease Control (CDC) in Atlanta to believe that the waste oil had been contaminated with a toxic substance. More than 3 yr elapsed, however, before the toxic agent was identified.

Contaminant Present

Contamination of the salvage oil resulted from the improper disposal of an industrial waste residue. The source of the contamination was traced to a trichlorophenol (TCP) production plant in Verona, Missouri, which was being leased by the Northeast Pharmaceutical and Chemical Corporation (NEPACCO). The production of TCP generated a distillation residue containing the highly toxic contaminant 2,3,7,8-tetrachlorodibenzo-p-dioxin (TCDD), an unwanted byproduct of the chemical manufacturing process.

The still residues were routinely stored in a tank on the Verona site, where they were allowed to accumulate until the tank was full and disposal of some of the material became necessary. Between February and October 1971, the Bliss Salvage Oil Company, which collected, stored, and resold waste oil from a large variety of sources, hauled six truckloads of still residues,

totaling 60,500 liters, from the Verona plant.¹ Most of the still residues were hauled to St. Louis, where they were mixed in a large tank with waste oil from other sources. Oil sold for re-refining or for use as a fuel oil or dust suppressant was drawn off the top of the tank and sludge collected at the bottom.

The Sontag Road area was identified by a former Bliss employee as having been sprayed with oil drawn from this tank. It appears likely that at least two loads of waste oil (22,700 liters total) containing an estimated 5 to 10 g of TCDD were applied to sites in the Sontag Road area at one time or another.²

Sampling and Analysis

In 1983, EPA Region VII personnel and their contractors collected several hundred soil and dust samples from the Sontag Road area. Soil samples were taken from the road shoulders, adjacent yards, and stream beds in accordance with well-documented methodologies.² Dust samples from building interiors were collected from household vacuum cleaners and portable Dust-busters. The highest levels of TCDD (588 ppb) were found in the parking lot of Mel's Tavern. Dust collected from the interior of the tavern contained 36 ppb (personal communication from G. E. Kepko, U.S. Environmental Protection Agency, Region VII, Kansas City, Kansas, January 20, 1984).

Health Hazard Evaluation

One of the most toxic substances known to man, TCDD has been linked to birth defects and is suspected of causing soft tissue sarcoma. The primary route of human exposure to dioxin is absorption through the skin; however, it may also be inhaled or ingested.

Approximately 60 persons reside within the contaminated Sontag Road area. When fire service personnel and patrons of Mel's Tavern (who were subjected to periodic exposure) are added, the total number of exposed persons reaches more than 300. Children were considered particularly susceptible because they had been observed walking barefoot on the contaminated road shoulders during the summer.

From the health effects evaluations by the CDC and others developed specifically for the numerous problem areas in central and eastern Missouri, it has been concluded that the general population's continuous exposure to TCDD levels in excess of 1 ppb in soil represents an unreasonable health hazard and provides adequate justification for mitigation actions to protect the public health. Dioxin concentrations in the soil at numerous locations around the Sontag Road area ranged from 60 to more than 500 times this action level.²

DECONTAMINATION STRATEGY

Sampling results in the Sontag Road area demonstrated the presence of widespread TCDD contamination. The EPA deemed it unreasonable to expect that residents of the area could voluntarily restrict access and exposure to dioxin-contaminated soil over the long term. Therefore, in July 1983, EPA requested funds under the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) to remove the immediate public health hazard and to prevent further spread of the contaminant. The request for funds was approved, and decontamination was initiated on August 1, 1983. The EPA's decontamination strategy was designed with the hope of eliminating the need to relocate residents and close area businesses for extended periods of time.

Target Levels

As cited previously, the CDC established an action level of 1 ppb for TCDD in dust and soil. Mitigative measures were required for all areas where TCDD concentrations exceeded this level.

Methods

Phase One operations, which were implemented within 48 h of the announcement of contamination levels to the public, included the following:

1. Vacuuming respirable dust from all paved surfaces in the site area that are contaminated (or suspected of being contaminated) by use of industrial-quality, air-powered vacuums equipped with high-efficiency particulate air (HEPA) filters for particulate removal.
2. Applying a nontoxic chemical spray dust suppressant to road shoulders and contaminated yards to prevent additional spread of contamination and to reduce exposures.
3. Paving the parking lot of Mel's Tavern and several private driveways with a temporary surface of minimum volume to permit continued use of these areas.
4. Vacuuming residences and businesses known or suspected of being contaminated, including 608 Sontag Road, Mel's Tavern, the fire station, and Horsefalls Residence.

The methods used to decontaminate both Mel's Tavern and the equipment used for collecting soil samples in the Sontag Road area are described here in greater detail.

Mel's Tavern--

Mel's Tavern, a single-story wooden building with a crawl space underneath and an attic, was built in the 1920's. The total floor area is approximately 420 m². The wood is deteriorating, and numerous cracks and holes are

evident in the walls and floors. Dust blows into the tavern through vents in the attic and through open windows in the summer. It is also tracked in from the parking lot on the soles of people's shoes. Inside the building the dust collects in the cracks and crevices.

The aim of the decontamination efforts was to remove dioxin-contaminated dust from the tavern. The entire structure and all of its furnishings were first vacuumed with high-powered vacuums equipped with HEPA filters. The walls, floor, ceiling, ductwork, furniture, knickknacks, etc., were then scrubbed down with soap and water and rinsed with plain water. Insulation in the attic, which had trapped contaminated dust over the years, was replaced with new insulation. The entire effort took six to nine workers 9 days to complete. Throughout this period, the tavern remained open for business, and the decontamination work had to be scheduled around the owner's operating hours.

The contaminated dust and insulation that were removed from the tavern were sealed in 55-gal drums and ultimately disposed of in a secure landfill. The wash and rinse waters were run through two filters (two 55-gal drums, one filled with sand and the other with activated carbon) and tested with a turbidity meter before being discharged to the ground on site. The discharge water was subsequently analyzed in the laboratory and found to contain no TCDD above the detection limit of 0.001 ppb. The drums containing the filter media were also disposed of in a secure landfill.

Equipment--

Soil samples taken in the Sontag Road area were collected with hand-picks. Cross-contamination between samples was avoided by decontaminating the picks after each sample collection.

The decontamination station consisted of two large metal tubs and one aluminum foil pan placed on a sheet of plastic spread over the ground. In the first tub, the picks were scrubbed with soap and water until visibly clean. This was followed by a series of four rinses using different agents (water, alcohol, 1,1,1-trichloroethane, and water). In each case, the rinsing agent was placed in a plastic squeeze bottle and squirted over the pick. The rinsate from the water and alcohol rinses was collected in the second large tub. The 1,1,1-trichloroethane rinsate was collected in the aluminum pan, poured into a glass sample jar, labeled, and returned to the lab for TCDD analysis. The wash and rinse waters and the foil pan were treated as contaminated wastes and disposed of appropriately.

Worker Protection

The cleanup contractor took several measures to ensure the health and safety of their employees while on site. As a standard practice, all employees receive yearly baseline physicals. In addition, the successful completion of a hazardous waste training course was required of all decontamination workers prior to commencing site operations. While on site, workers were

Appendix F: Sontag Road Area

required to wear Level C protective clothing and equipment to provide skin and respiratory protection from exposure to dioxin-contaminated particulates. Level C protective equipment consists of disposable Tyvek suits, gloves, boots, and air-purifying respirators equipped with particulate filters. During the hot months, each worker's pulse and blood pressure were monitored for signs of heat stress. The quickest route to the hospital had been planned, and the buddy system was in effect at all times. As of January 1984, no accidents or incidents of toxic exposure had been reported.

Costs

The costs for sampling and analysis of approximately 400 soil and dust samples taken in the Sontag Road area totaled \$730,000. Phase One decontamination operations cost an additional \$341,000. Of this, \$11,000 was spent cleaning Mel's Tavern. The value of the tavern has been estimated at \$150,000; thus the Phase One costs of decontaminating the building appear to have been justified (personal communication from G. E. Kepko, U.S. Environmental Protection Agency Region VII, Kansas City, Kansas, January 20, 1984).

EVALUATION OF DECONTAMINATION EFFECTIVENESS

Six weeks following the Phase One decontamination efforts, the cleanup contractor returned to Mel's Tavern to collect a dust sample for determining the effectiveness of decontamination. The TCDD concentration in this sample was measured at 22 ppb, considerably higher than the 1 ppb action level. Apparently, the deteriorated condition of the building made complete removal of the contaminated dust impossible. Also it was suspected that tainted soil from the crawl space underneath the tavern was blowing up through the cracks in the floorboards.

The EPA regional office recommended that the entire tavern be vacuumed and scrubbed again and that the walls be sealed with paint and shellac. They further recommended that the old wooden floor be replaced with new plywood subflooring and linoleum. The EPA headquarters, however, would not approve the plan, as these actions would have, in effect, constituted capital improvements to the site. Thus, further decontamination was limited to repeated vacuuming and scrubbing until the 1 ppb action level could be achieved.

REFERENCES FOR APPENDIX F

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APPENDIX G

CASE STUDY: ONE MARKET PLAZA OFFICE COMPLEX*

BACKGROUND

On May 15, 1983, a fire occurred in a Pacific Gas & Electric (PG&E) transformer vault serving the Steuart Tower of the privately owned One Market Plaza (OMP) office complex in San Francisco, California. Flames and smoke from this fire contaminated parts of the OMP building with several types of toxic chlorinated organic substances.

Interim guidelines established during the week following the fire served as operational goals for decontamination efforts where toxic substances were found as a result of the fire. During the decontamination process, only cleanup personnel wearing protective equipment were allowed to enter the contaminated areas. Final target levels and analytical procedures were developed by the San Francisco Health Department with the help of many experts (both individuals and organizations).

Major decontamination efforts focused on vault surfaces; interior and exterior surfaces of air handling systems; walls, ceilings, and floors; and equipment such as coils, switch gear, distribution panels, motor control centers, and computer control panels.

The wide variety of decontamination methodologies used included grit-blasting, dismantling, pneumatic chipping and jackhammering, insulation removal, solvent washing, physical scraping, vacuuming/dusting, hydroblasting/waterwashing, strippable coatings, and K-20 sealant.

Contractor personnel provided management and planning support during the cleanup operation and were responsible for actual decontamination activities.

The closed portions of the OMP complex were reopened by the San Francisco Health Department on March 22, 1984, and completely reoccupied shortly thereafter.

* Source of information: Personal communication from V. G. Rose, Pacific Gas and Electric Company, San Francisco, California, April 17, 1984.

NATURE AND EXTENT OF CONTAMINATION

The nature and extent of contamination were determined by collecting samples of various media and analyzing them for the suspected contaminants.

Contaminants Present

Various parts of the building were contaminated with polychlorinated biphenyls (PCB's), polychlorinated dibenzodioxins (PCDD's), and polychlorinated dibenzofurans (PCDF's) as a result of the flames and smoke generated during the fire.

Sampling and Analysis

Routine air, liquid, wipe, and bulk samples were taken from the vault and inside the building over a period of time from May through November 1983. Final sampling was conducted in December 1983 and March 1984. The samples were analyzed for PCB's, PCDD, and PCDF. Results of the PCB analyses show that levels dropped over time as decontamination efforts progressed. Data from the PCDD and PCDF analyses were not available. Methodologies for sample collection were also not available.

DECONTAMINATION STRATEGY

The decontamination strategy required the establishment of target contaminant levels and the determination of appropriate decontamination methods for specific media. Decisions were made weighing decontamination costs versus equipment replacement costs. Equipment procurement lead times, probability of success in decontamination, etc., were also considered.

Target Levels

Initial interim guidelines were developed in the week following the fire. Final guidelines for contaminant levels allowing re-entry and quantitation procedures were developed as cleanup efforts progressed and a number of experts were consulted.

Interim Target Levels--

Interim guidelines developed by the San Francisco Health Department with input from all parties involved were established as follows:

- ° 1.0 μg PCB's/ m^3 (air)
- ° 1.0 μg PCB's/ 100 cm^2 (surfaces)
- ° 0.5 ng total PCDD-PCDF/ 100 cm^2 (surfaces)

Appendix G: One Market Plaza Office Complex

Final Re-entry Target Levels--

Final re-entry guidelines were developed by the San Francisco Health Department in consultation with the California State Department of Health Services, the New York State Health Department, the Centers for Disease Control, the National Institute for Occupational Safety and Health, private consultants, and academic scientists.

The established guidelines for safe airborne and surface levels for re-entry into the decontaminated areas at OMP were as follows:

- ° 1.0 μg PCB's/ m^3 (air)
- ° 100 μg PCB's/ m^2 (surfaces)
- ° 10 pg total PCDD-PCDF/ m^3 (air)
- ° 3 ng total PCDD-PCDF/ m^2 (surfaces)

In the establishment of these guidelines, background levels of PCDD-PCDF were assumed to be zero.

Guidelines for safe airborne and surface levels for re-entry into the PG&E vault were established as follows:

- ° 1.0 μg PCB's/ m^3 (air)
- ° 1 mg PCB's/ m^2 (surfaces)
- ° 80 pg total PCDD-PCDF/ m^3 (air)
- ° 24 ng total PCDD-PCDF/ m^2 (surfaces)

At exposure levels at or below the above guidelines, it is believed that anyone entering the OMP building and working in the complex 8 h/day and 5 day/week for 40 yr would experience no additional risk of cancer, reproductive, embryotoxic, or other acute or chronic health effects beyond those of a similar nonexposed population (personal communication from V. G. Rose, Pacific Gas & Electric Company, San Francisco, California, April 17, 1984, and May 22, 1984.)

All samples were collected according to written protocols approved by the San Francisco Health Department. These levels are based on a sampling and analytical uncertainty of at least 20 percent for PCDF-PCDD analysis and 15 percent for PCB's. Based on these figures and the large safety margins built into the risk assessment, any deviations in actual contaminant readings were assumed not to result in an increased risk to exposed populations.

Methods

Four specific components of the building complex were targeted for decontamination procedures, and procedures consisted of many state-of-the-art methodologies. The simultaneous cleanup of the building components required the use of different and multiple decontamination procedures. In all instances, the objective was to remove 100 percent of the PCB and PCDF-PCDD contamination from the OMP complex.

Vault Surfaces--

Decontamination procedures used on the transformer vault surfaces consisted of physical removal of portions of the concrete surfaces by gritblasting, dismantling, and pneumatic chipping and jackhammering.

The initial step in the process was to grit-blast all contaminated surfaces to remove gross contaminants from the concrete. A glass-like "black sand" material was used as the gritblasting material. All concrete block walls were then dismantled and removed by sawing the structures into removable sections, lowering them to the vault floor, and removing leftover materials. Pneumatic chippers, also known as scarifiers, were then used to chip away 1.5 cm of concrete from the ceiling and remaining walls. Lastly, jackhammers were used to remove 15 cm of concrete from the vault floor. This resulted in exposure of the structural building slab.

Air Handling Systems--

More than 35 air handling systems, including such components as insulated fan housing and blower units and ductwork, had been contaminated by permeating smoke. Cleanup of these surfaces consisted of removing insulation, solvent washing, physical scraping, vacuuming/dusting, waterwashing, and dismantling.

Initially, all interior insulation in the air handling systems was removed. The remaining surfaces were solvent-washed and physically scraped to remove stubborn glue residue. Exterior insulation on ductwork was vacuumed and wiped. The fan housings, other metal exterior surfaces of fan systems, and blower units were then vacuumed and detergent-washed.

Access to the interior of metal ducts was through holes cut in the ductwork. To minimize the number of holes to be cut, cleanup personnel entered the duct system whenever possible. Surfaces were then vacuumed to remove ambient dust particles and washed with a detergent solution.

Because of their adsorptive nature, rubber and synthetic components of the fan systems could not be cleaned. Therefore, they were physically dismantled and disposed of.

High contamination levels prompted the removal and disposal of all the components of two air handling systems and portions of two additional systems.

When accessibility problems prevented the manual cleaning of portions of two ventilating systems located in sealed concrete shafts, decontamination procedures consisted of placing a large suction at the base of each vertical duct and using pressurized air to loosen and dislodge particulate matter adhering to the interior surfaces.

Walls, Ceilings, and Floors--

All sheet rock and concrete walls, ceilings, and floors in contaminated rooms were first vacuumed and detergent-washed. Strippable coatings were

Appendix G: One Market Plaza Office Complex

applied to some concrete surfaces, allowed to react for 24 to 48 h, and then peeled off. Concrete surfaces close to the vault were also coated with K-20.

Equipment--

An innovative procedure was developed for decontamination of expensive equipment at the OMP complex that could not be manually cleaned. This equipment included fan system heating and cooling coils, electrical switch gear, distribution panels and motor control centers, and computer control panels for building life support systems. The decontamination technique consisted of first building a containment structure around the item to be decontaminated and then washing the item with a high-pressure solvent spray. The solvent was collected at the bottom of the containment area, and the liquid was returned to a holding tank, where it was filtered and distilled to remove the contaminants.

Worker Protection

During decontamination procedures, only persons wearing standard personal protective equipment were allowed in the contaminated areas. When cleanup efforts had brought contaminant levels down to those stated in the interim guidelines, restricted access was permitted for further decontamination efforts.

Costs

As of March 1984, total costs for the cleanup of the OMP complex were estimated to range from \$15 to \$20 million.*

EVALUATION OF DECONTAMINATION EFFECTIVENESS

The closed portions of the OMP complex were judged to be successfully decontaminated as measured by the final sampling results. The OMP complex was reopened by the San Francisco Health Department on March 22, 1984, and completely reoccupied shortly thereafter.

* U.S. Environmental Protection Agency. Polychlorinated Biphenyls (PCB's); Manufacture, Processing, Distribution in Commerce and Use Prohibitions; Use in Electrical Transformers. Advance Notice of Proposed Rulemaking. 49 FR 11073, 1984.

APPENDIX H

CASE STUDY: FRANKFORD ARSENAL

BACKGROUND

From its inception in 1816 until its closure in 1977, the Frankford Arsenal in Philadelphia, Pennsylvania, was the site of various military activities and accomplishments. Major operations at the 45-ha arsenal included munitions manufacture, materials and research development programs, development of propellant- and cartridge-actuated devices, and procurement missions. Its closure was part of the Army's worldwide realignment program to improve management, to exploit available technology to the fullest, and to reduce costs.

In June 1977, the office of the project manager for Chemical Demilitarization and Installation Restoration (now the U.S. Army Toxic and Hazardous Materials Agency, USATHAMA) assumed responsibility for the decontamination and cleanup of the Frankford Arsenal. Several processes were involved in the development and implementation of the decontamination program. The time frame and scale of these processes are presented in this case study.

Following a records search to identify possible contaminants, USATHAMA awarded a sampling contract in March 1978. The contractor completed the sampling survey in November 1978.

Procurement activities were initiated in February 1979, and a contract calling for a multiphase, onsite decontamination and cleanup program was awarded in September 1979.

The decontamination and cleanup program was organized into three phases:

- ° Phase I--Demonstration of the effectiveness of various decontamination and cleanup methods.
- ° Phase II--Generation of standard operating procedures for control and direction of the decontamination operations.
- ° Phase III--Actual decontamination and cleanup of the Arsenal.

This case study is concerned mainly with Phase III. Persons having a strong interest in the initial phases can obtain information from USATHAMA, Aberdeen Proving Ground, Maryland.

NATURE AND EXTENT OF CONTAMINATION

The nature and extent of contamination of the Frankford Arsenal were determined by sampling various media for the suspected contaminants identified in the literature search. These included low-level radiological wastes, explosive/pyrotechnic residues, organic chemicals, and inorganic chemicals (heavy metals).

Contaminants Present

A detailed sampling survey of the Arsenal revealed the following contaminants: explosives, asbestos, radiological wastes, and heavy metals. Several specific wastes within the explosive, radiological, and heavy metal categories were identified.¹

Explosive contaminants were the greatest in number. Major residues included pentaerythritol (PETN), styphnic acid, trinitroresorcinol (TNR), nitrocellulose (NC), nitroglycerine (NG), trinitrotoluene (TNT), dinitrotoluene (DNT), N-tetranitro-N-methylaniline (tetryl), and cyclotrimethylenetrinitramine (RDX). Although tests covered many specific radiological contaminants, only depleted uranium and radium were found in significant quantities at the Arsenal. The heavy metal residues present consisted of lead, cadmium, chromium, and mercury.

Specific structures contaminated at Frankford were buildings, sumps, vents, and sewers. Eight buildings were contaminated with explosives, 12 with radiological residues, and 135 with heavy metals. The vent of one building was contaminated with explosives, and radiological contaminants were found in the vents of four buildings. The sumps associated with six buildings were contaminated with explosives, and sumps in 23 buildings were contaminated with heavy metals.

Sampling and Analysis

Samples of various media were collected and analyzed for explosive, asbestos, radiological, and heavy metal contamination.

Explosives--

In buildings where explosives were historically used, samples were collected and analyzed for RDX, TNT, 2,4-DNT, 2,6-DNT, tetryl, NG, PETN, and NC. Samples were collected with acetone-saturated cotton swabs. The acetone was contained in a 2-dram vial, and wooden-stem Q-tips were used for application. Five 5-cm-diameter circles distributed at the four corners and center of a 1-m² area were swabbed for building surfaces, as was one 5-cm-diameter circle for vents. The Q-tip was dipped in acetone before and after each circle was swabbed.¹

Sump samples for explosives were collected with a vacuum pump. A length of Tygon tubing sufficient to reach the bottom of the sumps was used to pump the samples out. Clean tubing was used for sampling each sump. Samples were stored in glass containers.

Analysis of the swab and sump samples was performed with a high-pressure liquid chromatograph (HPLC). Eight buildings, one vent, and six sumps were determined to be contaminated with explosives at levels above the detection limit of the instrument. When surface areas were confirmed to be contaminated with explosives, a match test was performed to determine ignitibility.

In buildings suspected of being contaminated with both heavy metals and explosives, air samples were taken to determine levels of airborne heavy metals prior to the explosive samples.

Radiological Residues--

Building and vent surfaces suspected of radiological contamination were sampled through surface smears. A filter paper disc with a 2.4-cm diameter was passed over a representative (usually approximately 100 cm²) portion of the surface in question by the tip of a thumb. Because the pressure-bearing portion of the filter paper disc was approximately 2 cm wide, the smear was about 50 cm long. The smear was applied in a Z or S pattern, and care was taken to avoid excess surface dirt. Duplicate smears were taken at one out of five locations.²

After the smears were taken, appropriate instruments were used to test the samples for radiological contamination. Areas that tested positive for contamination were identified by painting a yellow border around them.

Sludge and water from sumps were simultaneously sampled for radiological contamination by filling a 1-liter plastic bottle. Approximately one-half to three-fourths of the bottle's volume was composed of sludge. A lid was placed on the bottle and secured with tape. The container was then labeled. When dry sludge samples were taken, the bottles were no more than three-fourths full of sludge material. Any suspected presence of explosive contamination was noted on the container and data sheet.

This same methodology was used for water samples except that samples were taken in half-gallon plastic bottles, and care was taken not to collect solid residues such as surface scum or sludge. Concentrations in effluent released to surface waters were averaged on a monthly basis.

Areas suspected of airborne radiological contamination were sampled by passing air through a filter paper. Lapel sampling pumps, air sampling pumps with glass fiber filters, and high-volume air samplers were used for this purpose. The sampler used, its flow rate, and the sampling time were recorded on a data sheet. The filter paper was placed in an envelope on which the serial number was marked.

Appendix H: Frankford Arsenal

In buildings where heavy metal and radiological contamination was suspected, airborne sampling for heavy metals and radiological air survey were performed simultaneously.

Heavy Metals--

Testing of heavy metal contamination of building surfaces and vents consisted of measuring airborne concentrations of mercury (Hg), cadmium (Cd), chromium (Cr), and lead (Pb). The concentrations of Cd, Cr, and Pb were determined by atomic absorption analysis of three filter samples. Samples were collected by use of cellulose ester (CE) air filters with 0.8- μ m pore size and an air-moving pump that operated 8 h at a flow rate of approximately 1500 cm³/min. The mercury concentration was measured by use of a mercury sniffer that operated with an air flow rate of approximately 750 cm³/min.

Sump samples were collected and analyzed for heavy metals in a manner similar to that used for explosive sump samples. Briefly, samples containing both water and sludges were collected by means of a vacuum pump. Enough Tygon tubing to reach the bottom of the sump was used for pumping the samples out. Clean tubing was used in each sump. Samples were stored in precleaned polyethylene containers.

Health Hazard Evaluation

Health hazards presented by the four categories of contaminants (explosives, asbestos, radiation, and heavy metals) are many and varied, and discussion of each is beyond the scope of this case study.

DECONTAMINATION STRATEGY

The strategy for decontamination activities first required that target contaminant levels be established first and that the appropriate methods for decontamination of specific media be determined. Worker protection and project costs were also considered.

Target Levels

A basis for declaring the Arsenal "decontaminated" and releasing it for unrestricted use was established by setting target levels for all specific contaminants. These target levels are presented in Tables H-1 (Explosives), H-2 (Heavy Metals), and H-3 and H-4 (Radiological Contaminants). Asbestos target levels are not included because the relatively small amounts of this contaminant found were in buildings that were ultimately burned to the ground.

TABLE H-1. SUMMARY OF TARGET LEVELS FOR EXPLOSIVES^{a,b}

Explosive	Surface, g/ml of extract
NG	40
PETN	50
RDX	1.0
TNT	1.0
2,4-DNT	1.0
2,6-DNT	1.0
Tetryl	1.0
NC	

^a Reference 1.^b Based on lowest detection limit of instruments available.TABLE H-2. SUMMARY OF TARGET LEVELS FOR HEAVY METALS^a

Heavy metal	Surfaces, $\mu\text{g}/\text{m}^3$	Sewers, mg/liter	Surface runoff, ppm
Mercury	1.6	0.005	0.01
Cadmium	1.6	0.1	0.02
Chromium	1.6	3 (total)	0.1 (hexavalent)
Lead	1.5	1	0.1

^a Reference 1.

TABLE H-3. SUMMARY OF TARGET LEVELS FOR RADIOLOGICAL CONTAMINANTS ON SURFACES^a

Nuclides ^b	Surfaces		
	Average ^{c,d,e}	Maximum ^{c,e,f}	Removable ^{c,e,g}
U-nat, U-235, U-238, and associated decay products	5,000 dpm α /100 cm ²	15,000 dpm α /100 cm ²	1,000 dpm α /100 cm ²
Transuranics, Ra-226, Ra-228, Th-230, Th-228, Pa-231, Ac-227, I-125, I-129	100 dpm/100 cm ²	300 dpm/100 cm ²	20 dpm/100 cm ²
Th-nat, Th-232, Sr-90, Ra-223, Ra-224, U-232, I-126, I-131, I-133	1,000 dpm/100 cm ²	3,000 dpm/100 cm ²	200 dpm/100 cm ²
Beta-gamma emitters (nuclides with decay modes other than alpha emission or spontaneous fission) except Sr-90 and others noted above	5,000 dpm $\beta\alpha$ /100 cm ²	15,000 dpm $\beta\alpha$ /100 cm ²	1,000 dpm $\beta\alpha$ /100 cm ²

^a Source: Reference 1.

^b Where surface contamination by both alpha- and beta-gamma-emitting nuclides exists, the limits established for alpha- and beta-gamma-emitting nuclides should apply independently.

^c As used in this table, dpm (disintegrations per minute) means the rate of emission by radioactive material as determined by correcting the counts per minute observed by an appropriate detector for background, efficiency, and geometric factors associated with the instrumentation.

^d Measurements of average concentration should not be averaged over more than 1 m². For objects of less surface area, the average should be derived from each such subject.

^e The average and maximum radiation levels associated with surface contamination resulting from beta-gamma emitters should not exceed 0.2 mrad/h at 1 cm and 1.0 mrad/h at 1 cm, respectively, measured through not more than 7 mg/cm² of total absorber.

^f The maximum contamination level applies to an area of not more than 100 cm².

^g The amount of removable radioactive material per 100 cm² of surface area should be determined by wiping that area with dry filter or soft absorbent paper, applying moderate pressure, and assessing the amount of radioactive material on the wipe with an appropriate instrument of known efficiency. When removable contamination on objects of less surface area is determined, the pertinent levels should be reduced proportionally, and the entire surface should be wiped.

TABLE H-4. SUMMARY OF TARGET LEVELS FOR
RADIOLOGICAL CONTAMINANTS IN WATER AND AIRBORNE SAMPLES^a

Nuclide	Sewers, $\mu\text{Ci/ml}$	Surface runoff, $\mu\text{Ci/ml}$	Airborne samples, $\mu\text{Ci/ml}$
H-3	0.1	0.003	2×10^{-7}
CO-60	0.001	0.00003	3×10^{-7}
Zn-65	0.003	0.0001	2×10^{-9}
Kr-85 (gaseous)	--	--	3×10^{-7}
Ag-110m	0.0009	0.00003	3×10^{-9}
Pm-147	0.006	0.0002	2×10^{-9}
Po-210	0.00002	0.0000007	7×10^{-12}
Ra-226	0.0000004	0.00000003	2×10^{-12}
Th-230	0.00005	0.000002	8×10^{-14}
Th-nat	0.00006	0.000002	2×10^{12}
U-nat	0.003	0.00003	5×10^{-12}
U-238	0.003	0.00004	3×10^{-12}

^a Source: Reference 1.

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There was some concern that unneutralized explosive material could be released in water, either to the surface or as runoff to the sewers. Therefore, target levels for explosives were based on the lowest available instrumentation detection limits, which were established by use of a signal-to-noise ratio equal to 3. After detailed testing, limits were agreed upon and specified in the contract.³

All established target levels for radiological contaminants were based on ANSI standards and CRC guidelines.³

Levels of surface heavy metal contamination were established by measuring airborne concentrations and determining that samples were below the maximum allowable concentrations of heavy metals set by the Surgeon General's Office. Water target levels as related to heavy metals were developed in accordance with Philadelphia's Wastewater Control Regulations (sewers) and the Delaware River Basin Guidelines (surface runoff).³

Methods

Meeting the goal of releasing the facility for unrestricted use required the implementation of several effective state-of-the-art decontamination methods. Cleanup techniques used were both contaminant- and structure-specific. Methods were developed from current state-of-the-art techniques; modifications and/or additions were made during Phases I and II of the cleanup program.

Explosives were decontaminated through flaming. Various types of flaming devices (e.g., floor flamers, wall flamers, and hand flamers) were used. Mass flaming (complete burndown) was performed in one area of the Arsenal.

Asbestos decontamination took the form of simple removal. The friable asbestos was removed and packaged for delivery to suitable burial grounds.

Decontamination methods for radioactive materials consisted of localized cleanup (hand wash and scrub), dry vacuuming and sweeping, high-pressure water treatment, detergent foam application and removal, physical removal, and sand blasting.

The heavy metal decontamination technique consisted of removing loose and flaked paint, preparing surfaces for painting, and subsequent painting with low-lead paint.

Priorities were established for decontamination efforts to maximize personnel protection. Explosives were removed first, followed by radiological residues and heavy metals. In areas that were mass-burned (because of explosive contamination), asbestos was removed before the burn-down was begun.

When structures were contaminated with a combination of wastes, the decontamination activities proceeded in the priority order. Except where noted, decontamination methods for multi-contaminant structures did not differ from the normal procedures described.

Explosives--

The buildings, vent, and sumps contaminated with explosives were decontaminated by use of a variation of the flaming process. This was possible because most buildings at the Arsenal were constructed of brick, concrete, metal-based, and clay-tile materials. Before the actual cleanup process began, safety considerations and requirements were developed, and all combustible materials were removed from the buildings.

Removal of combustible materials--Preparation of the buildings for flaming involved the removal of all combustible materials and obstructions that would hinder the process. The operation was performed with nonsparking tools and under wet conditions. The specific equipment required included nonsparking tools (including wrecking bars), water and a water sprayer, safety glasses, coveralls and gloves, hard hats with face polycarbonate shields, an air compressor, containers for the removed material, an air-powered circular saw, spare saw blades, penetrating oil, a fire extinguisher, plastic hats, and dust masks.

When the equipment was assembled, the removal process began. Penetrating oils were applied to all joints, screws, and nuts to be removed. Wooden surfaces were wetted and then removed with spark-proof tools. Metallic materials were removed and hand-flamed. Caution was used not to allow any friction-producing tools to reduce the size of removable materials until the debris was flamed in the area to be cut. After removal, materials were packaged in boxes and marked according to building location and debris type.

Remote flaming--Remote flaming (through the use of a floor flamer and wall flamer) was used in the larger buildings. Equipment and materials required included a flame torch drive system, assorted hand tools, a measuring tape, a 5-kVA or larger generator, hard hats with shields, a fire extinguisher, dust masks, and NIOSH-approved respirators.

When the equipment and materials were assembled at the building sites, areas were roped off and signs were posted to prevent entry. Flamers were then set up to cover as large an area as possible, and torch heads were positioned approximately 10 cm from the building surface. Operators then retreated to a safe area and notified the fire department of the operation so that a standby fire truck could be secured. Torches were ignited and traversed at 300 cm/min. Cracks were flamed for 60 s. If residue flowed from the cracks, the flamers were set to traverse the crack at 300 cm/min. Ten min were then allotted for cooling purposes. Upon reentering the area, decontamination personnel repositioned the torches to cover the next building surface. The above steps were then repeated until all walls, floors, and exposed ceilings had been flamed.⁴

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Remote flaming was used at a few buildings that were contaminated with both radiological and explosive residues. When it appeared the flaming process would spread the radioactive contamination, local enclosures were used to control the airborne radioactivity.

Hand flaming--Hand-flaming techniques supplemented the remote flammers when areas were inaccessible to the floor and wall units and also in the smaller buildings. Equipment used for hand flaming was the same as that for remote flaming with a few modifications. The remote flaming torch drive system was replaced by a flame torch (1.8-m-long handle) with a 75-degree offset and brush tip; and the assorted hand tools, measuring tape, and generator required for remote flaming were replaced by safety glasses, flame-retardant coveralls, and protective aprons.

After the equipment and materials were assembled and the fire department had been notified, the hand-flaming process began. Torch heads were positioned approximately 10 cm from the surface and were moved at the rate of 3 m/min. Workers concentrated on cracks for 1 min; if residue flows were produced, the cracks were traversed at 3 m/min. Hand flammers were used on any areas contaminated with explosives that had not been flamed with the remote flammers.

The single set of ductwork contaminated with explosives was hand-flamed and subsequently removed and shipped to a suitable waste burial site.

Sump decontamination with charcoal briquets--The technique used to flame the six contaminated sumps was based on obtaining a temperature that would result in either decomposition or ignition of the residues in the sump. First, aerator lines using compressed air were installed, and the sumps were partially filled with charcoal. Igniter units made from a combination of explosives were then placed in the sump. A layer of kerosene-soaked charcoal was placed on top of the igniter units, and the sumps were filled to capacity with charcoal. The charcoal bed was then ignited and allowed to burn for an extended period of time.

Mass burning of the 400 area--The 400 area at the Frankford Arsenal was a 3.6-ha tract consisting of 32 small buildings, sumps, and sewer systems. Because these buildings had a low value and a history of explosives manufacturing, this area was cleared of any free structures or other contaminants (asbestos) and then demolished and leveled to grade.

The approach to this effort consisted of removing all friable asbestos and ceiling panels. In a manner similar to that used for sump cleanup, the buildings and sumps were loaded with charcoal, soaked with kerosene, and remotely ignited. Two detonations occurred during the burn, and observers reported "feeling the ground shake."

When the burning was completed, footing, sumps, and sewers were excavated and the buildings were demolished according to traditional industrial demolition procedures.⁵

Secondary waste impacts--Waste forms generated by the flaming methods consisted of combustible (wood) and noncombustible materials (metallic structures) possibly contaminated with explosive residues. These wastes were surface-treated through flaming or flashing and disposed of as scrap or in a landfill.

Asbestos--

Because asbestos contamination was present only in the 400 area, the magnitude of the cleanup effort was insignificant compared with the decontamination procedures for explosives, radiological residues, and heavy metals. Therefore, only a brief description of asbestos cleanup is presented in this case study.

Asbestos shingles and pipes insulated with asbestos were on the outside of the buildings in the 400 area. Steam and air pipes insulated with approximately 5 cm of asbestos generated 44 m³ of removable material. Twenty-seven m³ of asbestos shingles were removed from the roofs of the buildings and covered walkways in the 400 area. The pipe insulation and shingles were treated separately.⁵ A notice of asbestos removal was submitted to appropriate local, state, and Federal agencies prior to starting the cleanup process.

Elevated pipes were lowered to the ground before any asbestos removal took place. The pipes were wetted, and the asbestos remained wetted throughout the entire handling process. Pipes on which the insulation was intact were then cut into sections, and the sections containing asbestos insulation were wrapped in 6-mil or thicker plastic sheeting. The sheeting was secured, and the wrapped pipe was placed in a roll-off container. When the container was filled, it was covered with a tarpaulin and transported to an approved landfill.

During removal of the shingles from the roofs, precautions were taken to prevent unnecessary breakage during the operation. The shingles were placed in a covered roll-off container (separate from the piping) and sent to an approved landfill for disposal. All OSHA, EPA, and associated state and local regulations and requirements were adhered to during all asbestos-removal operations.⁵

Radiological Residues--

Twelve buildings and four vents contaminated with radiological residues were decontaminated by cleaning, removal of surface material, and removal of other structures (drains, overhead facilities). Safety considerations were addressed and preparation plans were developed before the decontamination process began.

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Preparation for decontamination--Initially, controlled areas around the buildings were established to prevent the possible spread of contamination during cleanup operations. These areas were sealed and isolated from the rest of the Arsenal. Any items that were to be decontaminated were wrapped in plastic and moved into one of the controlled areas. Loose debris was sprayed lightly with water and then boxed for disposal. Any structures (drains, light fixtures, conduits) interfering with access to ceiling, wall, and floor surfaces were dismantled and packaged. Main water and steam lines were capped, and electrical conduit circuits were disconnected at the source when these items were removed. When significant amounts of dirt or dust remained on the floor, the floor was vacuumed or swept to minimize particulate activity during cleanup procedures.⁶

Buildings--Radiological decontamination of buildings was organized into sections. In most cases, cleanup procedures started with the initial stage and proceeded onward. Surveys were taken at the end of each stage; if the contaminant levels of particular areas or rooms were below the target levels described in Table H-3, the cleanup equipment was decontaminated as necessary and the areas were sealed off to prevent recontamination. If the survey showed higher contamination levels than allowable, the next cleaning stage was begun. For some ceilings, walls, and floors (depending on the type and condition of the surface and contamination activity), decontamination procedures were begun at one of the higher stages.⁶

Equipment needed for all cleanup stages included a wet/dry vacuum cleaner, high-pressure water equipment with variable pressure controls, assorted janitorial supplies, detergents, caustic, chipping devices, (chipping hammers, scabblers, grinders), brushes, NIOSH-approved respirator equipment, work clothes and other protective equipment, radiological instrumentation, ladders and approved platforms, an air compressor, a fire extinguisher, and containers for the disposal of contaminated materials.

Initial Stage--Localized Cleanup, Hand-Wash, and Scrub. For small isolated spots of contamination, detergent and brushes were used to clean up the residues.

Stage I--Dry Vacuuming and Sweeping. When all equipment required for this stage was assembled and checked over, workers donned the protective respiratory gear and clothing and started vacuuming at the ceilings and tops of the walls and worked their way down to the floors. Extra attention was given to cracks, crevices, and hard-to-reach areas.

Stage II--High-Pressure Water. First, all drains, cracks, and doorways were sealed off to prevent flow of effluent into outer areas. All needed tools and equipment were then assembled and checked for operational efficiency. After donning their protective clothing and face shields, workers began the spray operation at the ceilings and tops of walls and proceeded downward to the floors, giving extra attention to

cracks and crevices. Afterwards, water rinse effluents were vacuumed or collected, and surfaces were allowed to dry. If surface surveys met the target levels established in Table H-3, effluent samples were sent for contamination analysis.

Stage III--Detergent Foam Application and Removal. Foaming was not used on radiological contamination of the fixed variety because it requires removal of the surface material.

Physical Removal. Chipping hammers, scabblers, grinders, and brushes were used to remove contaminated surfaces. This was the primary method used at this installation.

Vents--In one building, two vents encased in concrete presented a removal and disposal problem. Therefore, they were cleaned in place by a sand-blasting technique, and the sand residue was shipped to a disposal site as a radiological waste.⁶

Secondary waste impacts--Secondary wastes generated by the radiological decontamination procedures consisted of contaminated wash and rinse waters, dry solid waste, and contaminated fixtures, conduits, drains, piping, and other structural materials.

Excess wash and rinse waters were collected in 55-gal drums, neutralized (if necessary), decanted, filtered, and analyzed. Water that met Federal and local requirements for wastewater was released to the sanitary sewer system. Water that failed to meet these criteria and contained above-limit concentrations of radioactivity was solidified by hydraulic (cement/fixation) procedures. If radioactivity levels were acceptable but other contaminants were present in above-limit concentrations, the water was trucked to a site licensed to handle the contaminant present.

Dry solid material and all contaminated fixtures were packaged in approved containers and disposed of in approved burial grounds. Uranium-contaminated waste was shipped to Barnwell, South Carolina, for burial; and radium-contaminated waste was sent to a Beatty, Nevada, disposal facility.

Heavy Metals--

The major source of heavy metal contamination in 135 buildings at the Arsenal was the lead-based paint that had been on the interior surfaces. A few of the buildings also were contaminated with mercury as the result of laboratory spills.

Buildings--Based on work done during Phase I of the cleanup program, airborne heavy metal residues in the buildings were found to be below target levels. Therefore, the only decontamination work required was the removal of loose and flaking paint, preparation of surfaces for painting, and subsequent painting to meet bioavailability requirements set forth by the Surgeon General. Approval granted to USATHAMA by the Surgeon General's Office to paint

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to a height of only 1.8 m limited bioavailability of the new paint to people who might occupy the buildings after their release by the Army.

Cleanup and painting of the buildings were contracted to a small local business firm. Their work consisted of removing loose and flaking paint from the walls, sweeping the floors, vacuuming building rafters, and applying a paint containing no more than 0.06 weight percent lead. The entire process took approximately 7 mo.

Sumps--The cleanup of 23 sumps contaminated with heavy metals was divided into water and sump sludge decontamination activities. The water layer in the sumps was analyzed and then discharged into the city sanitary sewer system following approval by local officials. Sludges remaining in the sumps were then removed and disposed of in an approved landfill. Empty sumps were thoroughly rinsed with high-pressure water and then sampled. Nine sumps in which the target levels for heavy metal contamination were still exceeded were backfilled with concrete to prevent further usage.⁷

Worker Protection

Safety requirements were based on Federal, local, and industrial practices. Workers went through a training program (overseen by the decontamination manager) in which all procedures were reviewed in detail. Periodic audits by quality assurance personnel ensured adherence to the specific procedures.

Prior to actual flaming for explosives decontamination, USATHAMA and the local fire department were notified. Fire extinguishers or hoses were made available to all operating personnel, and specific procedures were developed in case of ignition. Worker protection was provided by fire-retardant coveralls, safety glasses, face shields, protective aprons, and nonsparking tools.

Until air samples were analyzed and it was determined that airborne lead levels were not being exceeded, workers wore appropriate respiratory protection.

Vacuuming equipment used for radiological decontamination was equipped with special exhaust high-efficiency particulate air (HEPA) filters to reduce the discharge of particulates to the atmosphere. Workers wore specially designed breathing apparatus during the vacuuming operation and safety glasses during the vacuuming, washing, and surface-removal operations. A fire extinguisher was present at all decontamination sites.

In addition to complying with OSHA requirements and local building codes for electrical equipment, all workers underwent a specialized training program, in which they had to review and understand all procedures before cleanup began. Quality assurance ensured adherence to specified procedures through periodic audits.

Costs

The cost of the decontamination and cleanup efforts at Frankford Arsenal totaled \$8 million.

EVALUATION OF DECONTAMINATION EFFECTIVENESS

After decontamination, all surfaces and sumps had explosive concentrations below the levels established in Table H-1. Asbestos-contaminated materials were removed and disposed of in an approved landfill. The 12 buildings contaminated with radiological wastes were certified as decontaminated when radiological surveys indicated surface and airborne radioactivity levels below the target values in Tables H-3 and H-4. Water was also cleared of radiological contamination; test results yielded values lower than those in Table H-4.

Frankford Arsenal was assessed as acceptably decontaminated for radiological contamination when appropriate tests had been performed for each 1-m² area and each effluent source or release pathway. Because many of the buildings were too large to be sampled in 1-m² areas, a partial inspection was performed, and the results were interpreted statistically to assure acceptability of these sites. Following all cleanup activities, the NRC toured the 12 buildings and verified their decontamination.

Cleanliness of surfaces after decontamination activities was determined through procedures similar to those used during initial sampling. As expected, airborne samples taken after the cleanup yielded heavy metal levels below the target levels; actually, airborne heavy metals concentrations were below these levels before any painting was done.⁷

Water from the sumps discharged in the city sewer also met the criteria in Tables H-2 and H-4. The 14 sumps not filled with concrete were thoroughly rinsed with high-pressure water. The water was sampled and found to meet Philadelphia's requirements for effluents in sewers.

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APPENDIX I

CASE STUDY: NEW ENGLAND OFFICE BUILDING*

BACKGROUND

In 1978 and 1979, a research program was undertaken at an office building in New England to 1) determine what commercial products could be used as encapsulants to contain, prevent, or restrict the release of asbestos fibers from friable asbestos-containing materials; 2) determine methods of evaluating commercial products for their efficiency as encapsulants; 3) determine the effectiveness of the evaluation methods by evaluating a group of commercial products; and 4) evaluate fiber release during field trials.

During the course of the research program, asbestos was applied to structures within the building, which were subsequently decontaminated through encapsulation. During these procedures, strict methodologies and regulations were followed.

NATURE AND EXTENT OF CONTAMINATION

Contaminants Present

Friable asbestos-containing material was spray applied to precast concrete slabs, steel support girders, and steel ductwork in a number of rooms. These areas were concealed by drop ceilings, which were attached 0.75 m below the precast concrete slabs.

Sampling and Analysis

As part of the test program, air sampling was conducted at field sites during encapsulant applications to determine the levels of worker exposure to airborne asbestos during different periods of the operation and to determine the settling rate of the asbestos fibers. Airborne asbestos was collected for subsequent microscopic analysis before, during, and after periods of room preparation, encapsulant application, and cleanup. Air samples were taken

* Source of Information: Battelle Columbus Laboratories. Final Report on Evaluation of Encapsulants for Sprayed-On Asbestos-Containing Materials in Buildings. U.S. Environmental Protection Agency, Industrial Environmental Research Laboratory, Cincinnati, Ohio. 1979.

Appendix I: New England Office Building

both in the encapsulant spray test room and in adjacent rooms. Outdoor ambient background samples were also taken. Each of four rooms evaluated independently showed similar results.

The indoor sampling procedure involved the use of a vacuum pump to draw the asbestos-laden air through high-efficiency membrane filters. A 47-mm-diameter, 0.4- μ m pore size polycarbonate membrane (Nuclepore) filter supported by a 5.0- μ m pore size cellulose acetate membrane (Millipore) filter was used to collect the fibers. Filters were placed at breathing height around the rooms in open-faced filter holders covered with a hood to prevent collection of unwanted debris, extremely large particles, or excess encapsulant mist. The sampling flow rate was set at 4.7×10^{-4} m³/s (1 ft³/min) and monitored with a rotometer throughout the sampling period. Sampling times were varied according to expected levels of airborne asbestos and observable loading of the filters.

Outdoor asbestos samples were taken with an RAC Model GMWL high-volume air sampler equipped with 0.45- μ m pore size cellulose acetate membrane (Millipore) filters at flow rates of 4.7×10^{-3} to 8.5×10^{-3} m³/s (10 to 18 ft³/min). These samples were subsequently analyzed to determine the ambient background level of airborne asbestos.

The collections of airborne fibers on Nuclepore filters (along with the Millipore backup filters) were stored and transported in 48 x 8.5 mm Millipore plastic petri dishes. Because it was not feasible to carbon-coat the Nuclepore filters at the collection site, extreme care had to be taken during transport to avoid dislodging the particles on the filter surface.

Upon its return to the lab, the collected sample was to be carbon-coated, the Nuclepore filter material dissolved away, and the fibers counted and measured in the configuration in which they had been collected by transmission electron microscopy (TEM). Both light and electron microscopic examination, however, revealed that the asbestos was unevenly distributed (often in clumps). This greatly reduced the chances for analysis of a representative area by TEM. In addition, the particulate concentration in some samples was too high to penetrate with the electron beam. These factors led to the conclusion that the particulate should be redistributed before attempting TEM analysis.

Not enough extraneous organic particulate material was present to warrant sample preparation by low-temperature ashing. Therefore, the particulate was removed from the Nuclepore filter by ultrasonic treatment in water containing a surfactant (sodium dioctylsulfosuccinate). The resuspended particulate was divided into 10-, 20-, and 70-ml aliquots, each of which was filtered, and the collected particulate was redeposited on separate 25-mm-diameter, 0.2- μ m pore size Nuclepore filters. This made it possible to select a particulate distribution suitable for analysis by TEM. The resulting data were subjected to computer analysis, and the results were expressed

in asbestos mass and numbers of fibers per m³ of sampled air. The computer also plotted fiber length, width, and length/width ratios versus cumulative number percent and calculated mean fiber lengths, widths, and length/width ratios.

Hazard Evaluation

Since the early 1970's, there has been an increasing awareness of the carcinogenic properties of asbestos fibers. One source of asbestos contamination to the general public is the deterioration of friable, sprayed-on asbestos-containing materials. These materials were used in the construction industry until the EPA banned them in 1978. Such asbestos fiber hazards are present in schools, apartments, night clubs, hotels, office complexes, and industrial plants where asbestos was used for thermal insulation, fireproofing, acoustical insulation, and decorative finishes. Microscopic, needle-like asbestos fibers are easily inhaled by inhabitants of these asbestos-containing buildings. Inhaled, asbestos fibers flow through the respiratory system and lodge in the lungs. Lung and other forms of cancer have been attributed to asbestos exposure.

DECONTAMINATION STRATEGY

Four encapsulants were evaluated in the field under conditions that would be found in public buildings containing friable asbestos contamination. The encapsulants were classified as "bridging" or "penetrating" encapsulants; one of the encapsulants was included in the former category and three in the latter. Bridging encapsulants are defined as those that form a continuous surface membrane over the asbestos-containing test matrix; penetrating encapsulants are defined as those that penetrate into the test matrix (from 0.6 to 3.2 cm) and thereby improve the strength of the encapsulating barrier.

Target Levels

Because the primary objective of the research operation was to evaluate potential encapsulants, no decontamination target levels were set. A secondary objective, however, was to detect any significant differences in concentration of airborne asbestos before, during, and after applying encapsulants.

Methods

The four encapsulants used for field evaluation were identified as follows:

- A--Bridging acrylic-based material
- B--Penetrating polyvinyl acetate copolymer-based material
- C--Penetrating acrylic-vinyl acetate copolymer
- D--Penetrating acrylic-modified polyester

Appendix I: New England Office Building

First, the four encapsulants were evaluated for fire resistance by a modification of ASTM Test Method E 162 (Surface Flammability of Materials Using a Radiant Heat Energy Source). The encapsulants were applied to three test panels: 1) asbestos board, 2) the test matrix, and 3) plywood. The asbestos board substrate was used as a control. Bridging encapsulant A was rated as having a Class "C" flame spread on the test matrix (Department of Housing and Urban Development Minimum Property Standards). Class "C" materials have limited application. Penetrating encapsulants B, C, and D were each rated as having a Class "A" flame spread on the same substrate.

Field trials were conducted during two different time periods; however, both trials were conducted on the same asbestos-containing substrate in different rooms. The test matrix was a friable asbestos-containing material (30 to 35 percent chrysotile) applied approximately 5.1 cm thick over a precast cement roofing and also on steel support I-beams. Although highly friable (released visible fibers when brushed), the material was in good condition (no loose material hanging down).

Bridging encapsulant A and penetrating encapsulant B were applied to the asbestos-containing material with an airless spray gun. The pump pressure was kept as low as possible to ensure a uniform spray pattern and minimum asbestos fiber release. The pump pressure resulted in a nozzle pressure of 7210 to 8270 kPa (1050 to 1200 lb/in²).

Bridging encapsulant A was applied in two coats. The first coat was applied as a mist coat with the encapsulant reduced approximately 10 percent with water. The second coat was applied without this reduction approximately 4 h after the first coat. The combination of the two coats formed a very tough elastic film about 0.3 cm thick over the surface of the asbestos. Penetration of the two coats was approximately 1.0 cm deep.

Penetrating encapsulant B was also applied in two coats. The first coat, however, was actually a "double coat." Because the encapsulant penetrated into the asbestos-coating material very quickly, after coating approximately a 1.1-m² area, the same area was recoated immediately. The second coat was then applied (in one pass) after the first "double" coat had been allowed to cure for a minimum of 12 h. The encapsulant penetrated up to 1.9 cm into the 9.1-cm asbestos-containing material.

In the second field trial, penetrating encapsulants C and D were applied to the test matrix by the same procedure used for the penetrating encapsulant in the first trial. With an airless spray nozzle and pump, the first coat was applied as a "double coat" and the second as a single coat.

Penetrating encapsulant C penetrated approximately 0.6 cm. Examination of a core sample indicated that the resin binder in the encapsulant material did not penetrate as deeply into the asbestos material as the water did. This resulted in a resin-rich top layer that sealed the surface and prevented the release of asbestos fibers. The surface, however, did not exhibit the desired impact-resistance.

Encapsulant D foamed during the airless spray application of the first coat. Therefore, the encapsulant was reduced with water for the second application. The foaming apparently restricted the penetration of the encapsulant. A core sample indicated that the maximum penetration achieved was only 1.0 cm. Although the foaming was overcome during the application of the second coat, no further penetration was achieved, possibly because the surface of the asbestos material was partially sealed by the first coat. Even though the encapsulant did not penetrate as desired, it did form a sealed surface over the asbestos material that could restrict asbestos fiber release.

Worker Protection

All personnel in the coating area and the control room were required to wear disposable protective clothing and a respirator. The protective clothing consisted of plastic disposal coveralls, polyethylene booties, a hood, and rubber gloves. Two types of respirators were used. The first type was a half-mask respirator with two Ultra Filters (cartridge type "H"). This respirator is approved by the National Institute for Occupational Safety and Health (NIOSH) and the Mine Safety and Health Administration (MSHA) for protection against dust and mist. The second respirator type was a 3M 09910 dust and mist respirator, which has NIOSH and MSHA approval for asbestos use. This disposable-type respirator proved to be ineffective in keeping a good seal around the face when stretching the neck to look overhead.

Costs

The cost for the encapsulation research study is not available.

EVALUATION OF DECONTAMINATION EFFECTIVENESS

The results of air sampling during spray application operations demonstrated how strongly activity affects the airborne asbestos concentration in a room. In all cases, peaks in airborne concentration corresponded to periods of high activity (ceiling removal, spraying, cleanup, ceiling replacement). Without exception, the highest levels were observed during the initial sealant application in each room. During periods of no activity, the airborne concentration of asbestos decreased drastically. Such a decrease may be attributed to gravitational settling of fibers or clusters of fibers.

The results strongly, if not conclusively, suggested that workers' activities serve to entrain and disperse previously deposited asbestos fibers in their work environment and thereby create a possible health problem. Each of the test areas evaluated had airborne concentrations below the NIOSH standard (2.0 fibers/cm³) during background and nonactive periods, but during each period of worker activity, the airborne concentration typically exceeded the standard by one or two orders of magnitude.

Appendix I: New England Office Building

The airborne asbestos concentration measured in a room adjacent to the room being sprayed varied in a manner similar to that of the sprayed room. Though attempts were made to isolate the spray rooms, elevated concentrations of asbestos in adjacent unsprayed rooms were undoubtedly the result of contamination from the spraying activities. This observation clearly demonstrates the need to isolate the room in which encapsulating procedures are taking place.

APPENDIX J

CASE STUDY: LUMINOUS PROCESSES, INC.*

BACKGROUND

The Luminous Processes, Inc., site is a defunct manufacturing facility near Athens, Georgia, in Clarke County. The company, which was operational from 1952 until 1978, utilized radioactive radium-226 and tritium to paint watch and clock dials. When the owners essentially abandoned the site in 1980, the levels of radioactive contamination in the soil and building exceeded the generally accepted criteria for permissible levels of radiation and radioactive material.

The State of Georgia made several unsuccessful attempts to get the company to decontaminate the building and surrounding property (approximately 0.4 ha). In March 1981, the Governor of Georgia appointed an interagency task force to determine the extent of the problem and seek the necessary financial assistance to decontaminate the property. During the succeeding months, personnel from the Georgia Department of Natural Resources (DNR) and the Department of Human Resources (DHR) conducted a detailed site evaluation. A decommissioning plan was prepared and later submitted to the U.S. Environmental Protection Agency (EPA) as part of pre-grant negotiations for financial assistance under the Comprehensive Environmental Response, Compensation, and Liability Act of 1980 (Superfund). In addition, the State of Georgia initiated legal proceedings against Luminous Processes, Inc., and its associated officers and directors. The Luminous Processes site was nominated as Georgia's top priority site for planned removal and appeared on EPA's October 1981 Interim Priority List of 115 uncontrolled hazardous waste sites.

On April 6, 1982, EPA and the State of Georgia entered into a Cooperative Agreement for remedial action at the Luminous Processes, Inc., site, whereby the Georgia Environmental Protection Division (EPD) was established as the lead agency. A contractor qualified to remove the contaminated soil was selected from among 39 interested firms. The scope of work included in the contract involved the excavation, packaging, shipment, and disposal of

* Source of Information: State of Georgia. Department of Natural Resources, Environmental Protection Division. Luminous Superfund Project Report: Remedial Action for the Removal of Ra-226 Contamination at the Luminous Processes, Inc. Site in Clarke County, Georgia. August 1982.

Appendix J: Luminous Processes, Inc.

425 m³ of soil and materials contaminated with radium-226 up to concentrations of 2000 picocuries per gram (pCi/g). The scope of work section of the contract was later amended to include removal of contaminated structures inside the building and septic tank tile field areas that were found to be more contaminated than the original site studies had indicated.

NATURE AND EXTENT OF CONTAMINATION

As part of a comprehensive feasibility study, the State of Georgia conducted a full-scale radiological evaluation of the Luminous Processes site and adjacent properties during the spring of 1981. The purpose of this evaluation was to determine the nature and extent of contamination and to use information gained in the evaluation process to identify decontamination options.

Contaminants Present

During the evaluation period, State personnel conducted direct radiation measurements (both onsite and offsite) to determine radiation exposure rates. In addition, soil samples were collected at established grid pattern locations and Ra-226 concentrations in picocuries per gram were measured as a function of soil depth.

The maximum observed onsite external radiation level was found to be approximately 1.5 millirems per hour (mrem/h). This means that the continuous presence of an individual in such an area for a period of 1 year could result in a theoretical dose of over 13,000 mrem. This theoretical level is more than 25 times the 500 mrem recommended by the National Council on Radiation Protection for exposure of the general public. Levels of Ra-226 wastes in onsite soils were found to be in excess of ambient (background) levels by more than a factor of 40. Approximately 425 m³ of soil was estimated to be contaminated. In addition, external radiation levels in soils immediately adjacent to and south of the site were found to be approximately two times background levels.

Inside the building, residual levels of removable alpha contamination were found to be present on certain walls and surfaces. In addition to the removable contamination, some fixed contamination was still found to be present in the building. The initial internal building evaluation did not include the extent and distribution of fixed contaminants within the building because of measurement problems created by interferences from the higher outside levels of radiation. After about two-thirds of the remedial action outside the building was completed, a detailed study was conducted inside the building.

Sampling and Analysis

An initial entry into the building was made to collect air samples for determination of radium daughter products in the air. While the highest

value of 0.003 working levels was well within permissible limits for occupation of the building during the survey, a decision was made to air out the building overnight by opening several windows and doors.

The next phase of the project was to lay out the building into definable survey blocks according to a grid system (Figure J-1). Because this had already been done by previous investigators, it was merely a matter of rechecking the grid system against reference points in the building. Next, an appropriate survey plan had to be devised to be sure all portions of the building were adequately covered during a survey for Ra-226 and its daughter products detectable in situ or in smearable form. Not only did interior surfaces such as floors, walls, ceilings, doors, and windows need to be surveyed for evidence of contamination, but remaining fixtures (sinks, toilets, light fixtures, heating ducts, roof structures, and subfloor/foundation) also required radiological testing.

The tests that were utilized in the assessment included in situ direct alpha activity testing, wet smearable (removable) testing for tritium (where appropriate), and special testing for activity found in paint and concrete. The building was also surveyed for direct gamma radiation with a low-level gamma radiation detector (Ludlum Model 19). Testing was conducted primarily on a regular, internal sampling basis (without biased scanning for hot spots) to build the statistical distribution necessary for a representative assessment. More than 200 in situ alpha tests, 200 dry measurable alpha tests, and 50 wet smearable tritium tests were conducted during this phase of the survey.

Three survey teams conducted the in situ direct alpha testing, utilizing either Eberline PAC-1 SATA-AC 3-7 or Ludlum 2200-PR-0190 alpha scintillation type survey instruments with wide-area contamination monitoring probes. The efficiency of each instrument was determined with an NBS traceable Am-241 alpha source (No. D963), and the effective area of each probe was determined so that the instrument readings (counts per minute) could be corrected to alpha activity in disintegrations per minute per 100 square centimeters (dpm/100 cm²). This survey was conducted at approximately 200 points over 1.5-m² subgrid block areas on the floor, walls, and ceiling of the building.

A second type of alpha radiation testing was conducted to determine dry smearable (removable) contamination from surfaces. This test consisted of wiping (smearing) the surface under test with an ashless-type filter paper over approximately a 100-cm² area. The smear paper was then counted with an alpha scintillation detector and a Ludlum 2200 scaler in the laboratory. The alpha detector-scaler system was calibrated with the Am-241 alpha source.

Tritium smears were taken with a cotton tip swab and placed in contact with a liquid scintillation counting solution. An Aston 1006 Manual Liquid Scintillation Counter was used to analyze the sample in the laboratory. Calibration was performed with an NBS traceable H-3 solution to determine a base efficiency. Internal standards testing was also performed on some off-color samples or if quenching determinations were necessary.

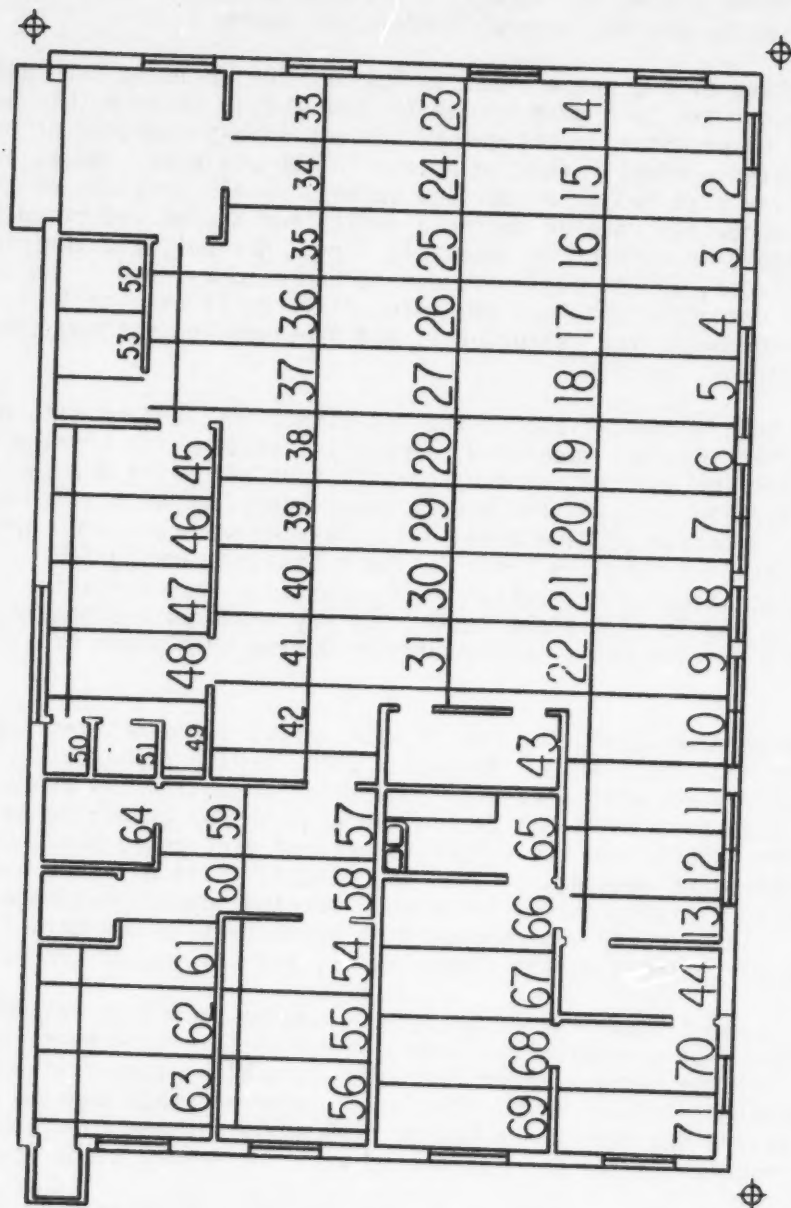


Figure J-1. Floor/ceiling map grid (floor/ceiling areas are numbered the same).

Typical data are presented by grid block location for groups of related grid blocks in Table J-1. For in situ direct alpha and dry smearable alpha tests, multiple test points were often measured within the group of related grid blocks to determine representative values. For this reason, the number of data points, the mean or average value of the data points, and the maximum observed value of the data points are given in the table.

A review of the data indicated that very little removable alpha activity existed. There were also small areas of tritium contamination, but the main problem was alpha contamination between the wall surface and the layer of paint. Contamination also existed at defined areas on the ceiling, doors, ductwork, and electrical wall panels.

Based on the data, it was decided that physical testing of the surfaces would be necessary to determine how deeply the contamination was embedded in the wallboard or painted surfaces, and to determine the best way to remove it. In this regard, a limited number of tests were performed on paint chips, wallboard chips, and concrete chips. The results indicated that, at the very least, the entire coat of paint had to be removed from the walls, along with some of the interior surface of the wall structure. Tritium was also found deeply imbedded in the wallboard itself.

Health Hazard Evaluation

Radium-226 is a radioactive isotope of radium having a half-life of 1620 years. Radium 226 emits ionizing radiation (gamma rays) that is destructive to living tissue. High levels of ionizing radiation cause somatic damage and may also induce genetic damage. Long-term effects of exposure to ionizing radiation may include increased incidence of carcinoma and shortening of the life span. Tritium is a beta-emitter; its radiotoxicity is very low. Once inhaled, tritium enters the normal body pool and in a short period becomes part of the body's metabolic scheme. Maximum permissible exposure limits to Ra-226 and tritium are discussed in the following section under the heading "Target Levels."

DECONTAMINATION STRATEGY

Making the site suitable for release for unrestricted use by the general public required that actions be taken to ensure the reduction of radiation and radioactive materials to acceptable levels. Of the options available to the State, the preferred method was the removal of the radiological contaminants from the site and ultimately disposing of them in an authorized radioactive burial facility. The bulk of the contaminants were in the form of radium-contaminated soil (425 m³) and, to a lesser extent, contaminated building materials. Under the decontamination and decommissioning plan submitted by the State, contaminated soil and building materials would be removed from the site until the target levels could be achieved.

TABLE J-1. TYPICAL BUILDING SURVEY DATA FROM INTERIOR WALLS

Bldg. area (grid)	Number of measurements	In situ alpha, dpm/100 cm ²		Smearable alpha, dpm/100 cm ²	
		Average	Maximum	Average	Maximum
1 ^a	1	1,870	1,870	ND ^b	-
14 ^a	1	1,870	1,870	ND	-
6	1	ND	-	ND	-
44	5	898	2,618	ND	-
71	4	608	2,431	6	26
68	10	823	3,740	ND	-
60	4	468	1,122	ND	-
52	12	1,683	14,960	8	20
43	8	95	375	3	13

^a Window sill.

^b ND - None detected.

Target Levels

The State of Georgia's position has been that decommissioning and decontamination work at Luminous Processes, Inc., should be conducted in such a manner that exposures to radiation and radioactive material would be as low as reasonably achievable (ALARA). Target levels for the building and the property and grounds were developed to serve as guidelines for attaining this objective.

Building--

The decontamination target levels for the building on site were based on U.S. Nuclear Regulatory Commission (NRC) guidelines for decommissioning nuclear facilities. Table J-2 indicates the allowable direct radiation levels and the allowable levels for Ra-226 (and associated daughter products) and other contaminants.

Property and Grounds--

The target levels for external (direct) radiation were established at an average of 10 microrads per hour ($\mu\text{R/h}$) above background (30 $\mu\text{R/h}$). Levels of 10 $\mu\text{R/h}$ for persons working in, residing in, or otherwise using the "released" area would, if continuously present in such an area, receive less than 20 percent of the National Council on Radiation Protection's recommended exposure for members of the general public. A level of 10 $\mu\text{R/h}$ was specified by the NRC in guidelines for decommissioning nuclear facilities.

With respect to the Ra-226 concentration in the soil, a target level of an average of 5 pCi/g above background (5 pCi/g) was established. This objective was based on draft guidance by the U.S. EPA.

The target level for tritium in soil was established as an average of 50,000 pCi/g. This objective could be exceeded in some instances provided potential surface water runoff from the property did not exceed 3,000,000 pCi/liter and that the potential for surface runoff to result in contamination of drinking water above the recognized Georgia Safe Drinking Water limit of 20,000 pCi/liter was minimal. This objective was based on NRC rulemaking March 11, 1981, concerning radioactive wastes. Basically, the NRC recognized an "exemption" for disposal of certain tritiated wastes provided the concentration of tritium did not exceed 50,000 pCi/g. The rulemaking change is currently incorporated in 10 CFR 20.306. The limiting value for tritium in surface runoff (3×10^6 pCi/liter) is based on NRC limits for release of licensed material to unrestricted areas via the waterborne pathway. The limiting value for tritium contamination in drinking water is based on the maximum contaminant limit for public drinking water supplies as specified in the Georgia Rules for Safe Drinking Water (Chapter 391-3-5, July 1977).

Table J-2. ACCEPTABLE SURFACE CONTAMINATION LEVELS

Nuclides ^a	Average ^{b,c,d}	Maximum ^{b,d,e}	Removable ^{b,d,f}
U-nat, U-235, U-238, and associated decay products	5,000 dpm α /100 cm ²	15,000 dpm α /100 cm ²	1,000 dpm α /100 cm ²
Transuranics, Ra-226, Ra-228, Th-230, Th-228, Pa-231, Ac-227, I-125, I-129,	100 dpm/100 cm ²	300 dpm/100 cm ²	20 dpm/100 cm ²
Th-nat, Th-232, Sr-90, Ra-223, Ra-224, U-232, I-126, I-131, I-133	1,000 dpm/100 cm ²	3,000 dpm/100 cm ²	200 dpm/100 cm ²
Beta-gamma emitters (nuclides with decay modes other than alpha emissions or spontaneous fission) except Sr-90 and others noted above	5,000 dpm $\beta\gamma$ /100 cm ²	15,000 dpm $\beta\gamma$ /100 cm ²	1,000 dpm $\beta\gamma$ /100 cm ²

- ^a Where surface contamination by both alpha- and beta-gamma-emitting nuclides exists, the limits established for alpha- and beta-gamma-emitting nuclides should apply independently.
- ^b As used in this table, dpm (disintegrations per minute) means the rate of emission by radioactive material as determined by correcting the counts per minute observed by an appropriate detector for background, efficiency, and geometric factors associated with the instrumentation.
- ^c Measurements of average contaminant should not be averaged over more than 1 m². For objects of less surface area, the average should be derived for each such object.
- ^d The average and maximum radiation levels associated with surface contamination resulting from beta-gamma emitters should not exceed 0.2 mrad/h at 1 cm and 1.0 mrad/h at 1 cm, respectively, measured through not more than 7 mg/cm² of total absorber.
- ^e The maximum contamination level applies to an area of not more than 100 cm².
- ^f The amount of removable radioactive material per 100 cm² of surface area should be determined by wiping that area with dry filter or soft absorbent paper, applying moderate pressure, and assessing the amount of radioactive material on the wipe with an appropriate instrument of known efficiency. When removable contamination on objects of less surface area is determined, the pertinent levels should be reduced proportionally and the entire surface should be wiped.

Methods

The majority of the work scope for the cleanup of the Luminous Processes site involved excavation, packaging, shipment, and disposal of soil contaminated with Ra-226. After about two-thirds of the remedial action outside the building was completed, a detailed assessment of the building was performed.

The building, a single-story structure with approximately 370 m² of space, was divided into 18 rooms, including watch dial and hand painting rooms, a dark room, an ultraviolet room, supplies and mechanical rooms, storage rooms, shipping room, restrooms, lunch/break room, offices, closet areas, and a garage. Prior to the State of Georgia's involvement in cleanup of the site, contractors for Luminous Processes had partially removed Ra-226 and tritium contamination from the building. During this decontamination effort, most of the readily removable contents of the building were shipped off for disposal. These included items such as tables, chairs, cabinets, exhaust hoods, sinks, air conditioners, assorted tools, office equipment (including a typewriter and printing machines), some doors and light fixtures, hot water heater, dollies, and floor tiles. In addition, the walls were washed to remove loose contamination before contaminated paint was stripped. Work had not progressed beyond this point since the end of 1979.

Before the State of Georgia could proceed with further decontamination, the overall structural integrity of the building had to be assessed. It was found that the center section of the ceiling and roof was in danger of collapse because frequent heavy rains had caused leakage through vent penetrations that had not been resealed after previous decontamination work. Large puddles of water and plaster chips from the ceiling covered nearly 50 percent of the floor space, and the ceiling was sagging from the pressure of water. Because of the obvious structural hazards, as well as the obstacles of debris and water on the floor, the following actions were taken: the ceiling was braced for safety purposes, the water and debris were removed from the floor and placed in drums for disposal, and the roof was covered with a temporary plastic cover to prevent further entry of water.

Following these structural modifications, the building was surveyed to determine the nature and extent of contamination, as outlined previously under "Sampling and Analysis." The results of the survey indicated that contamination had penetrated the paint and wallboard. The most cost-effective means of achieving decontamination was determined to be removal of all painted wallboard.

Interior wallboard was removed from the building studs, broken up into small pieces, and packaged in DOT-specification 17H drums for shipment to a hazardous waste disposal site in Richland, Washington. In addition, it was determined that a small area around each door knob on the doors to the interior rooms was contaminated with alpha radioactivity. Rather than remove the entire door, the contaminated areas were removed from the door by sawing out the surrounding sections, which were then placed in drums for shipment to the

disposal site. The fuse boxes and electrical panels were found to be contaminated on both inside and outside surfaces. They were removed, crushed, and placed in barrels for shipment. Contaminated area spots were also found on window sills, light fixtures, and the heating ductwork. Table J-3 presents representative data for a number of these areas. After several physical removal tests were performed, it was determined that a variety of techniques could be employed to decontaminate the area so that shipment to the disposal site in Richland, Washington, would not be necessary. For example, the window sills were treated with paint remover and sandpapered to remove the contamination. The light fixtures and ductwork were carefully removed and taken outside the building, where as much paint as possible was stripped by use of a high-velocity jet washer. The remaining areas were further sanded and monitored to determine that target levels had been met. These decontaminated fixtures were then crushed and transported for disposal in the metals disposal area of the Clarke County Sanitary Landfill.

Finally, other remaining areas (such as toilets and sinks) were surveyed and found to be free of radioactive contamination. One of the last studies involved the complete breaching of the concrete floor pad and removal of a sample of the underlying gravel and soil support structure. An analysis of the material showed that it was not contaminated with radioactivity.

Worker Protection

One of the primary objectives during cleanup work at the Luminous Processes site was to keep external and internal exposure to radiation and radioactive materials as low as reasonably achievable (ALARA). A system for personal protection and exposure monitoring was established to meet this objective. This system included the following items: whole body radiation counting, bioassays, radiation dosimetry, breathing zone air sampling, respiratory protection, and protective clothing. As a result of the exposure controls enforced during the cleanup, no personnel were unduly exposed to radioactive materials. Thus, the stated objective of keeping exposures ALARA was achieved.

Whole Body Radiation Counting--

All workers whose efforts could routinely put them in direct contact with contaminated material were checked for radiation exposure by counting in a NaI whole body counter before, during, and after the project. None of these counts showed a Ra-226 level above the minimum detectable level of 2 nanocuries (nCi).

Bioassays--

Indirect bioassays were made of the urine of persons working inside the Luminous Processes building to be sure they had not ingested excessive amounts of tritium. The highest value obtained was 11 ± 3 pCi/ml, well within safe limits.

TABLE J-3. TYPICAL BUILDING SURVEY DATA FROM
INTERIOR STRUCTURES (EXCLUDING WALLS)

Building area (grid)	Structure	Average gross alpha, dpm/cm ²
14	Window sill	1,870
20	Heating duct	1,065
25	Heating duct	852
35	Door (around knob)	2,805
42	Fuse box	3,740
43	Door (around knob)	7,480
46	Dirt under floor slab	ND ^a
49	Heating duct	1,065
62	Floor	1,520
65	Heating duct	3,195
68	Heating duct	4,473

^a ND - None detected.

Radiation Dosimetry--

External exposures were monitored by use of thermoluminescent dosimeters (TLD's) assigned to each person entering the site. Thirty-five individuals were assigned dosimeters. The average exposure of these individuals, including background, was 18.5 mrem; the maximum exposure was 80 mrem.

Breathing Zone Air Sampling--

For determination of the potential inhalation hazard due to airborne contamination, workers in areas likely to pose an airborne hazard were monitored by lapel or breathing zone samplers similar to those used in uranium mines. Such samplers utilize a battery-powered pump to draw a measured amount of air through a filter that collects airborne particulates. The filter is later analyzed for radioactive content. In general, workers in the drum-loading hopper or in other dusty operations, such as demolition of the wallboard or septic tank, were sampled.

Respiratory Protection--

The use of respiratory protection was limited to activities conducted inside the building and served mainly to protect workers from dust from the wallboard, not from airborne radioactive materials. All workers inside the building during the removal of building materials wore full-face, air-purifying respirators. The cartridges used in these respirators, however, also provided protection from airborne radioactive materials.

Protective Clothing--

The use of protective clothing by onsite personnel served a dual function--that of preventing direct skin contact with radioactive materials (thereby avoiding the possibility of radioactive materials on the hands being ingested during eating, smoking, or other activities) and preventing the spread of contamination. All persons working on the site were required to wear long-sleeved coveralls, gloves, and either disposable boots or heavy-duty boots that remained on site. For safety reasons, all persons on the site were also required to wear a hard hat. Persons performing a task having a high probability of contamination were required to wear a disposable paper suit over the coveralls.

Upon leaving the site, all persons were required to remove all protective clothing in the contamination reduction area. Disposable items were discarded in a plastic trash can liner, which eventually was placed in a drum along with contaminated soil. Nondisposable items, such as coveralls, hard hats, boots, and cloth gloves, were left on site until they could be surveyed for release. After removing their protective clothing, workers washed their faces and hands in the contamination reduction area, and then checked themselves with a Geiger counter.

All items leaving the site were surveyed for contamination before release. A log book was maintained that showed the type of items, the name of the person performing the survey, and whether or not the item was released

from the site. Several sets of coveralls were found to be contaminated above release limits and were discarded along with the disposable items. No equipment was found to be contaminated above release limits.

Costs

Under the Cooperative Agreement between the State of Georgia and the EPA, the State agreed to pay 10 percent of the total project cost; EPA agreed to finance the remaining 90 percent.

During the course of the remedial action, the contract was amended twice to incorporate additional scopes of work not included in the original contract. These included decontamination of the interior of the building and removal of contamination in areas previously unidentified. The resulting total project cost for the Luminous Superfund Project was \$754,394, which included the costs for building decontamination, compared with an initial estimate of \$812,921, which did not include any building decontamination costs.

EVALUATION OF DECONTAMINATION EFFECTIVENESS

The interior of the building has been decontaminated within the established criteria, but a major safety hazard continues to exist because of the rapidly deteriorating condition of the structure. The water-logged ceiling is expected to continue to place enough stress on the roof to widen the existing cracks and holes, and at some time, the entire roof will cave into the building. For this reason, the building has not been released; it remains locked and posted to prevent access.

APPENDIX K

CASE STUDY: CHEMICAL METALS INDUSTRIES, INC.*

BACKGROUND

Until its bankruptcy in August 1981, Chemical Metals Industries, Inc. (CMI) occupied two pieces of property in the Westport section of Baltimore, Maryland--one at 2001 Annapolis Road (Site 1) and one at 2103 Annapolis Road (Site 2). The two sites are separated by approximately 15 to 20 private residence row houses. Land use in the immediate surrounding neighborhood is a mixture of residential and commercial.

Operations conducted by CMI included the manufacturing of copper sulfate and copper hydroxide, and the recovery of precious metals from waste chemical solutions, and the printing of circuit boards. Site 1 was used for storage of miscellaneous solids (in drums), large quantities of scrap metal and acids, and other caustic and neutral waste liquids. This site (a former Sinclair gasoline station) consisted of a storage garage and adjoining yard. Site 2 comprised the office, laboratory, and manufacturing center for CMI. It included a building that housed company operations and an adjoining yard with numerous large (19,000-liter) above-ground storage tanks. Local residents and former CMI employees indicated that precious metals reclaiming had been conducted at this location since the 1950's.

Approximately 2 weeks before CMI filed for bankruptcy in August 1981, a Maryland Office of Environmental Programs inspector spotted the abandoned CMI operation. Subsequent investigations led State and Federal officials to conclude that immediate site remedial action (using Superfund monies) was warranted. Conditions were such that chemical substances abandoned on the site might react and cause a fire or explosion in the surrounding residential neighborhood.

Using Superfund resources, both pieces of property were remedied and put back into public use. Site 1 (the former CMI chemical storage yard) is now a neighborhood park. Site 2 (the former CMI manufacturing facility) is now used by the Maryland Department of Health as office and storage space.

* U.S. Environmental Protection Agency (Region III). Federal On-Scene Coordinator's Report. Chemical Metals Industries, Inc., Baltimore, Maryland. Immediate Removal Project. Philadelphia. Undated.

NATURE AND EXTENT OF CONTAMINATION

Site 1 contained approximately 1500 severely deteriorated plastic and metal drums piled haphazardly on top of one another. Liquids from some of the drums were leaking onto the ground. Markings on the drums indicated that at one time they contained, and may have still contained, corrosive liquids, cyanide-bearing compounds, and ammonia-bearing compounds. Twenty drums contained organic solvents. Four underground storage tanks were located on the site; one contained suspected waste oil and the other three contained gasoline and water. Organic vapors were detected in samples of soil and groundwater from the site. Rainfall was carrying a blue-green material offsite, and this material was impacting walkways and streets and draining into storm sewers. Analysis of the liquids in the drums showed no commercially significant levels of precious metals. Analysis of soils from the site indicated cadmium levels above EP toxicity values (i.e., greater than 1 mg/liter in the EP extract).

Site 2 contained 15 processing, chemical, and waste storage tanks, some of which were open. The tanks were filled with varying amounts of liquid and crystalline material. Approximately 100 drums filled with acids, caustics, salts, and wastes were also stored there. Sampling of the drums confirmed the presence of cyanide- and ammonia-bearing materials and corrosive liquids. One drum containing acid was reported to be fuming. Another 175 drums at the site contained solids and sludges of unknown composition. A vault at the site contained approximately 12 boxes and 12 bags of solid and powdered metals and other miscellaneous items. The metal stored in the vault was later confirmed to be zirconium, which is unstable as a powder. (In bar form, the zirconium metal is stable; however, a spontaneous chemical reaction may occur if it is dropped.) Small quantities of numerous reagents were found in the laboratory and in laboratory storage areas. Low concentrations of hydrogen cyanide and organic vapors were detected through air monitoring at the site.

Chemical analyses of the contaminated soil samples taken from the site indicated that the material would be acceptable for disposal at a permitted hazardous waste landfill. Groundwater samples taken from monitoring wells at the site were bluish-green.

Major concerns for both sites included 1) imminent threat of fire or explosion in the residential neighborhood, either from the actions of vandals or because of the chemical incompatibilities of the materials in the deteriorating drums; and 2) potential hazard to the public and the environment posed by runoff that could impact Gwynns Falls, a tributary of the Patapsco River.

Extent-of-contamination surveys and helicopter overflights indicated that most of CMI's hazardous materials had not contributed to any offsite environmental degradation.

DECONTAMINATION STRATEGY

Target Levels

Target levels for decontaminating buildings and structures apparently were not established. Rather, cleanup generally focused on the analysis, identification, and removal of chemicals in containers and the identification of potentially incompatible wastes that could lead to fire or explosion if allowed to contact each other.

Soil removal at the site was guided by the RCRA EP Toxicity characteristic defining hazardous waste (see 40 CFR 261.24). Soils were determined to be hazardous and were removed if levels of metals in the extract from the test exceeded the established criteria of 100 times drinking water standards.

Methods

At Site 1 (the CMI storage yard), more than 1500 plastic and metal drums were removed. Approximately 3800 liters of liquids (mostly waste oil and mixtures of gasoline and water) were pumped from the four underground tanks at Site 1. After they were emptied, these tanks were filled with a concrete slurry to prevent further use and to fill the void. All above-grade structures on Site 1 were razed and removed, along with contaminated soil, to a hazardous waste landfill. One remaining wall, which was shared with an adjoining residence, was left standing; this wall was sandblasted to remove contamination. After the removal of all hazardous materials and other debris, Site 1 was graded, capped, and sodded. The site is now used as a playground for neighborhood children.

At Site 2 (the CMI main operations center), approximately 19,900 liters of acidic solutions and 31,400 liters of basic/neutral solutions were pumped from the 15 above-ground storage and processing tanks. After careful removal of the liquids from these tanks, the tanks themselves and all chemical processing equipment were removed. In addition, approximately 100 drums of acids, caustics, salts, and other wastes and 175 drums of solids and sludges of unknown composition were removed. These materials were classified as hazardous wastes and removed to a permitted disposal facility.

An unstable structure at the rear of Site 2 was removed. Electricity was restored to the remaining building, and the front and side walls were sandblasted. The yard was paved after cleanup and surface grading. The building and yard of Site 2 are now used by the Maryland Department of Health as additional office and storage space.

Worker Protection

Site safety plans were written for both sites. These plans required medical examinations and training for cleanup personnel, outlined the site monitoring program, described general site safety rules, established zones of

contamination containment, and identified levels of protective equipment and evacuation signals.

The monitoring program was designed to track NH_3 , HCN, and explosive organic levels in the air at the site. Notably, at air concentrations between 2 and 10 ppm, cyanide respirators were required. Below 2 ppm, normal protective equipment was sufficient; levels above 10 ppm signaled an evacuation of all personnel from Zones 2 and 3 to the clear zone (Zone 1). The three zones of contamination containment and levels of protective equipment that were required are outlined for each site:

Site 1: Zone 1 included those areas outside Zones 2 and 3. It was designated as a Clean Zone into which no uncontained waste or contaminated equipment or personnel could be introduced. No respiratory protection or protective clothing were required in this area.

Zone 2 was defined as the area bordered on the south by the block wall surrounding Site 1, on the east by a line that encompasses the eastern end of the decon trailer, and on the west by a line that encompasses the dumpster boxes and trucks or trailers being loaded with waste or empty drums; it also includes the sidewalks on the south side of Clare Street and Clare Street up to the north curb. Respiratory protection as necessary (cartridge/canister respirator, airline gas mask, or self-contained breathing apparatus) was worn when the task being performed warranted it. As a minimum, workers wore plastic-coated Tyvek or rain gear and gloves when loading empty drums onto trucks or trailers. Gross decontamination of personal protective equipment and other equipment was performed in this area before that equipment left Zone 2.

Zone 3 was defined as the area within the cement block wall and building at Site 1. Minimum personal protective equipment included either a one-piece acid suit or rain gear or better, PVC boots with steel toe and shank or better, PVC gloves or better, and self-contained breathing apparatus or airline full-face mask with 5-min escape bottle or better. All openings were taped shut. Personnel were always accompanied by another individual when in Zone 3.

Site 2: Zone 1 included those areas outside Zones 2 and 3. It was designated as a Clean Zone into which no uncontained waste or contaminated equipment or personnel could be introduced. No respiratory protection or protective clothing were required in this area.

Zone 2 was defined as the area bordered on the south by the southern set of Railroad tracks bordering Site 2; on the east by the outer northbound lane of Annapolis Road and the contaminated side of the decon trailer on the north by the center line of the decon trailer extended to the CMI building; and on the west by the facade

Appendix K: Chemical Metals Industries, Inc.

of 2103 Annapolis Road. Respiratory protection (cartridge/canister respirator with acid gas cartridge/canister, airline gas mask, or self-contained breathing apparatus) was worn when the task being performed warranted it. As a minimum, workers wore plastic-coated Tyvek or rain gear and gloves when loading empty drums onto trucks or trailers. All personnel exiting this area were decontaminated. Gross decontamination of personal protective equipment and other equipment was performed in this area before that equipment left Zone 2.

Zone 3 was defined as the area within the chain-link fence and the facade of 2103 Annapolis Road. Minimum personal protective equipment included either a one-piece acid suit or a two-piece rain suit, PVC outer boots with steel toe and shank protection, acid-proof gauntlet style gloves or better, and SCBA or airline full-face mask with 5-min escape bottle or better. All openings were taped shut. Personnel in Zone 3 never worked alone and maintained radio contact with an individual in Zone 1 who was aware of emergency notification procedures.

Costs

Initial estimates of the total cleanup effort for Sites 1 and 2 ranged from \$58,000 to \$83,000 and 1 week's time. Actual cleanup activities took place over a 2-mo period between October 19 and December 18, 1981. The total cost of all cleanup and remediation activities exceeded \$325,000. More than \$200,000 of Superfund resources were committed. In addition to these funds, the city of Baltimore contributed \$35,000 in the form of police and fire protection during the removal of certain hazardous materials from the sites. The State of Maryland contributed approximately \$90,000 in redeveloping both pieces of property into their current uses.

EVALUATION OF DECONTAMINATION EFFECTIVENESS

Details on how building decontamination efforts were judged to be effective have not been reported. It would appear that visual inspections of the premises following sandblasting and structural removal operations were used. Chemical analyses were used to judge the effectiveness of removal operations involving contaminated soils.